(12) UK Patent (19) GB (11) 2 390 628 (13) B

(45) Date of publication: 17.03.2004

(54) Title of the invention: Wellbore casing repair

(51) Int Cl^7: **E21B 29/10**

(21) Application No: **0324174.2**

(22) Date of Filing: **31.10.2000**

Date Lodged: **15.10.2003**

(30) Priority Data:
(31) **06162671** (32) **01.11.1999** (33) **US**

(62) Divided from Application No
0212443.6 under Section 15(4) of the Patents Act 1977

(43) Date A Publication: **14.01.2004**

(52) UK CL (Edition W):
E1F FLA

(56) Documents Cited:
GB 2373524 A **GB 2356651 A**
WO 2001/018354 A1 **WO 1998/000626 A1**

(58) Field of Search:
As for published application 2390628 A *viz:*
UK CL (Edition V) **E1F**
INT CL^7 **E21B**
Other: **Online: EPODOC, WPI & JAPIO**
updated as appropriate

(72) Inventor(s):
Robert Lance Cook
David Paul Brisco
R Bruce Stewart
Reece Edward Wyant
Lev Ring
James Jang Woo Nahm
Richard Carl Haut
Robert Donald Mack
Alan B Duell
Andrei Gregory Filippov
Kenneth Michael Cowan
William Joseph Dean

(73) Proprietor(s):
Shell Oil Company
(Incorporated in USA - Texas)
910 Louisiana Street, Houston,
Texas 77252-2463,
United States of America

(74) Agent and/or Address for Service:
Haseltine Lake & Co
Imperial House, 15-19 Kingsway,
LONDON, WC2B 6UD, United Kingdom

2390628

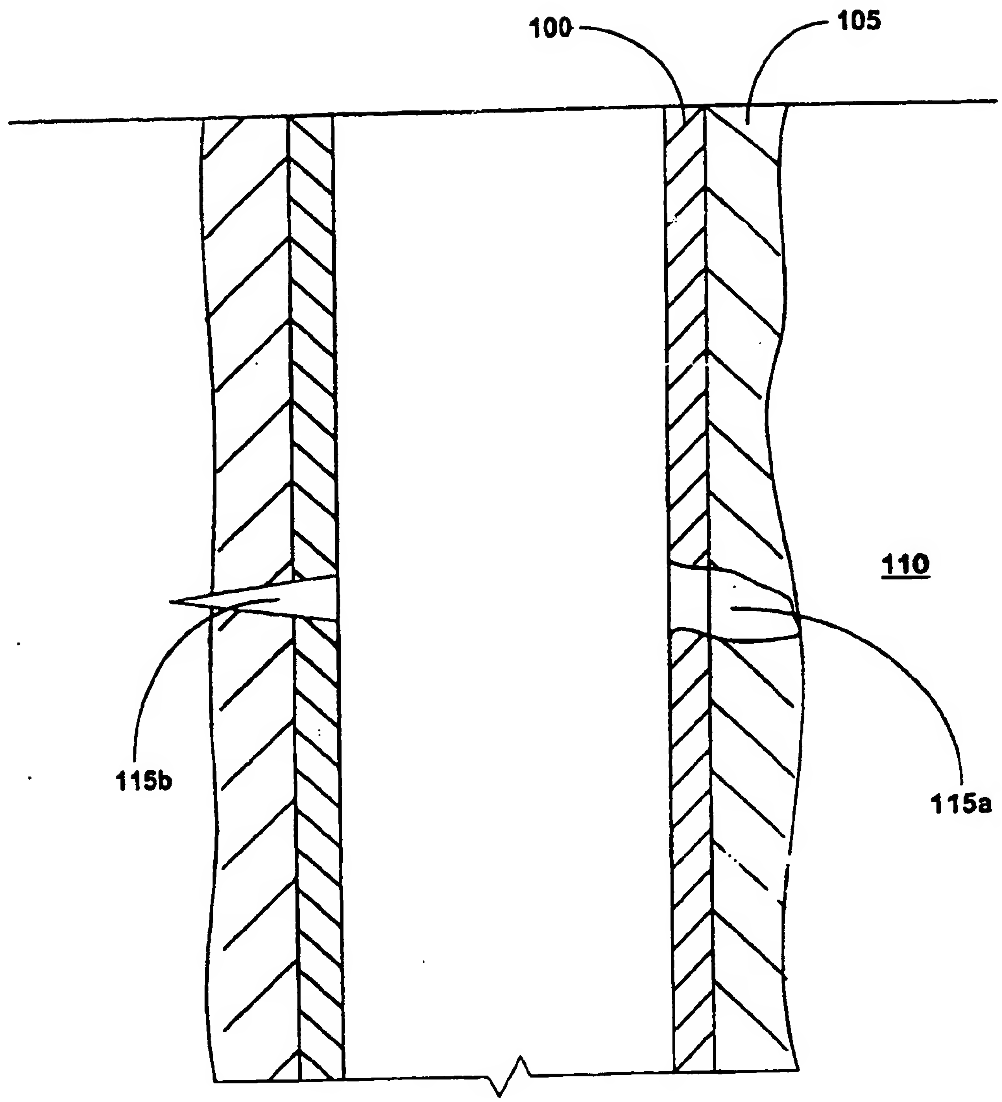


FIGURE 1

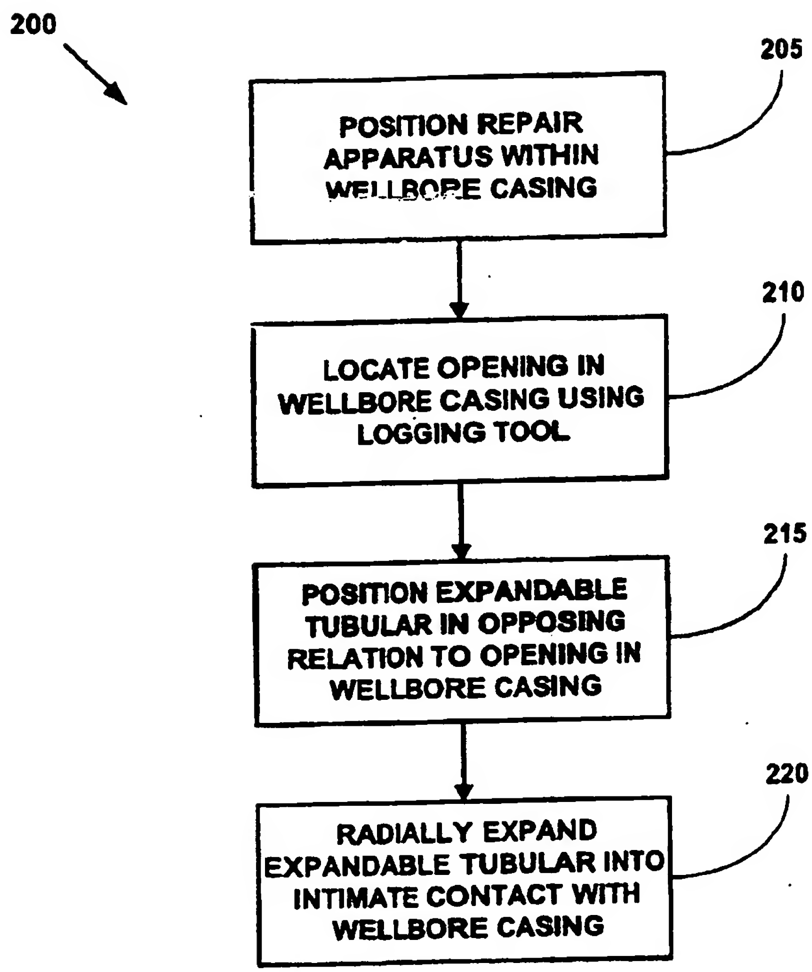

200
POSITION REPAIR APPARATUS WITHIN WELLBORE CASING
205
LOCATE OPENING IN WELLBORE CASING USING LOGGING TOOL
210
POSITION EXPANDABLE TUBULAR IN OPPOSING RELATION TO OPENING IN WELLBORE CASING
215
RADIALLY EXPAND EXPANDABLE TUBULAR INTO INTIMATE CONTACT WITH WELLBORE CASING
220

FIGURE 2

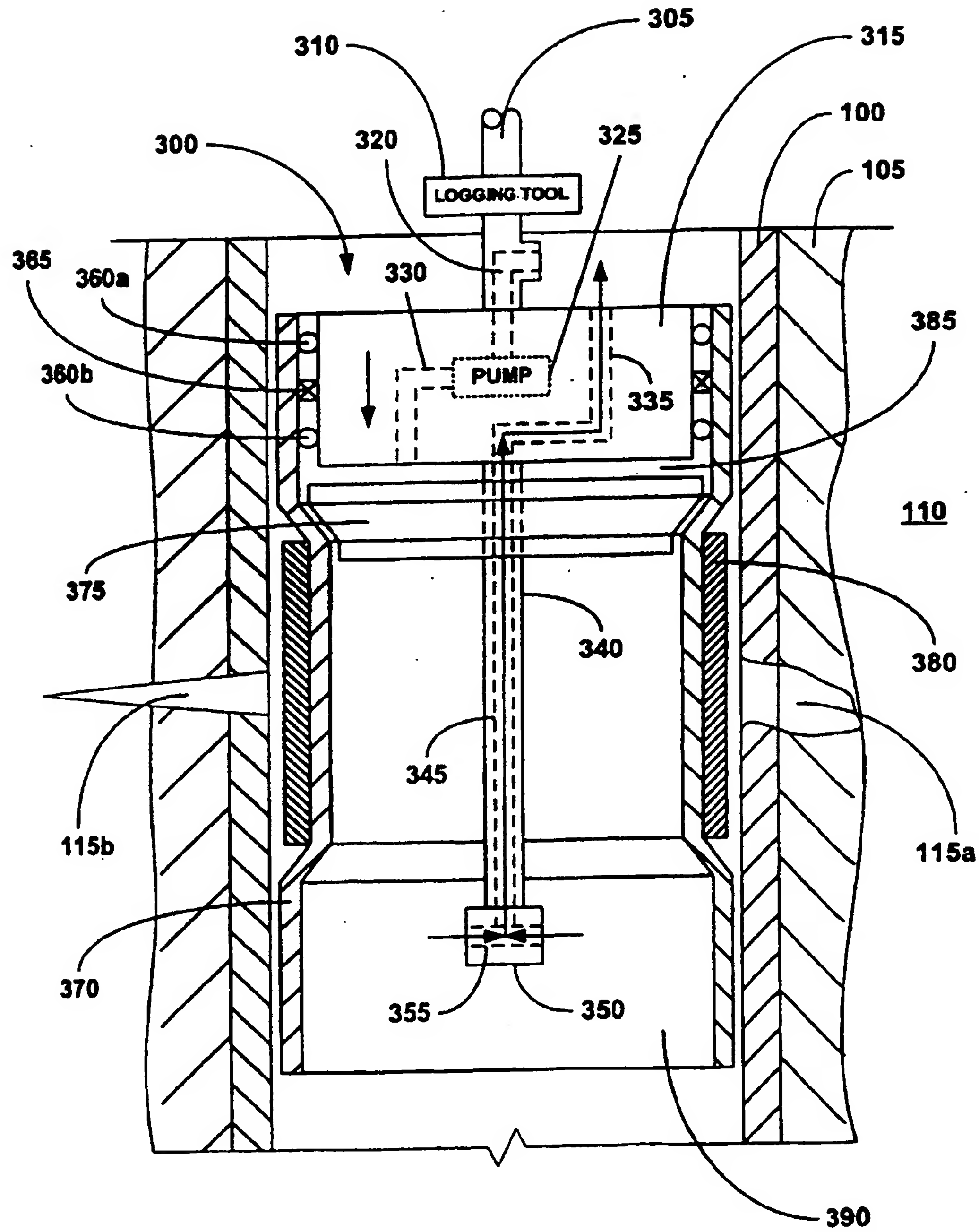

305
310
315
100
105
300
320
325
LOGGING TOOL
365
360a
330
PUMP
335
360b
385
110
375
340
380
345
115b
115a
370
355
350
390

FIGURE 3a

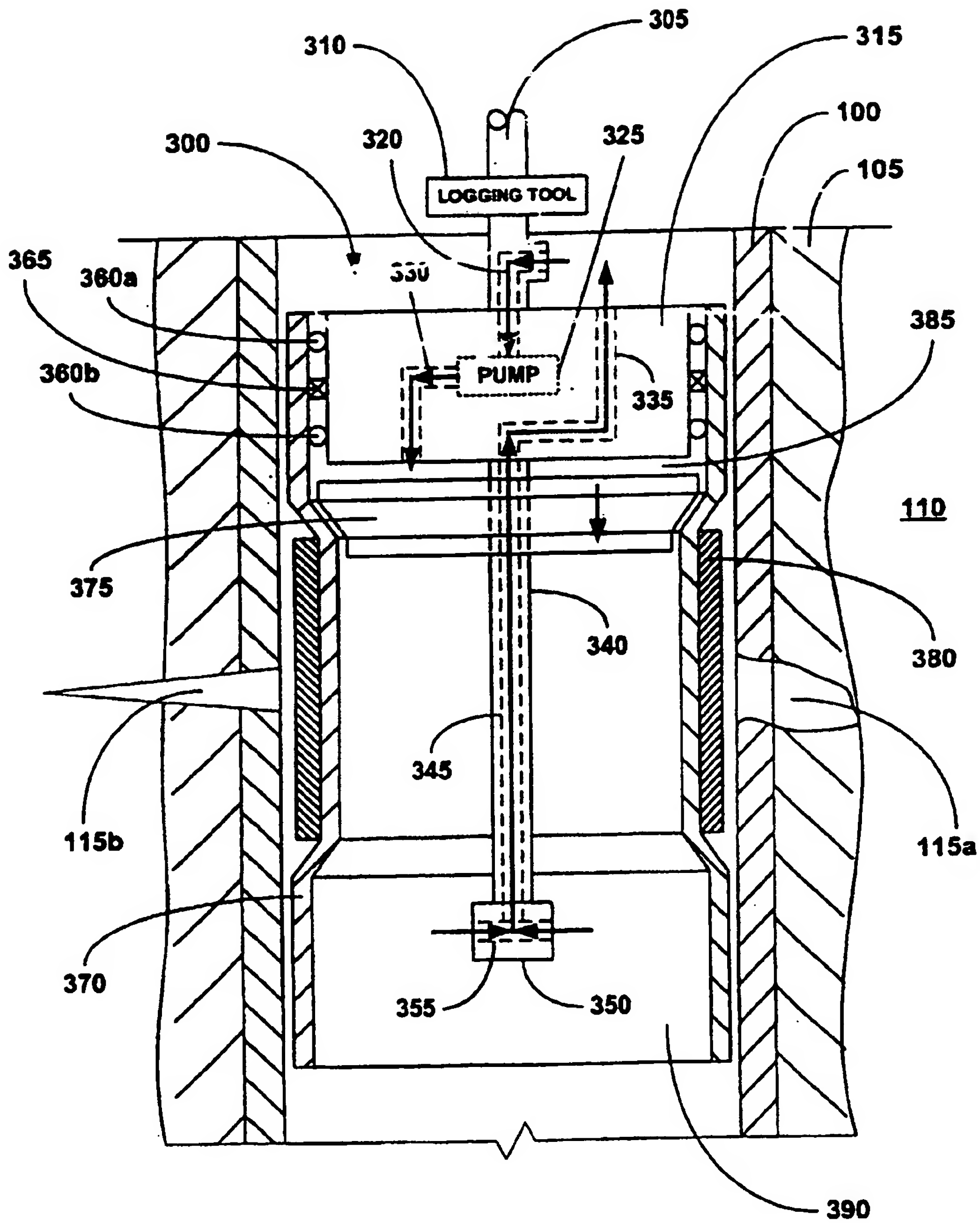

305
310
315
100
300
320
325
105
LOGGING TOOL
365
360a
330
385
PUMP
360b
335
110
375
340
380
345
115b
115a
370
355
350
390

FIGURE 3b

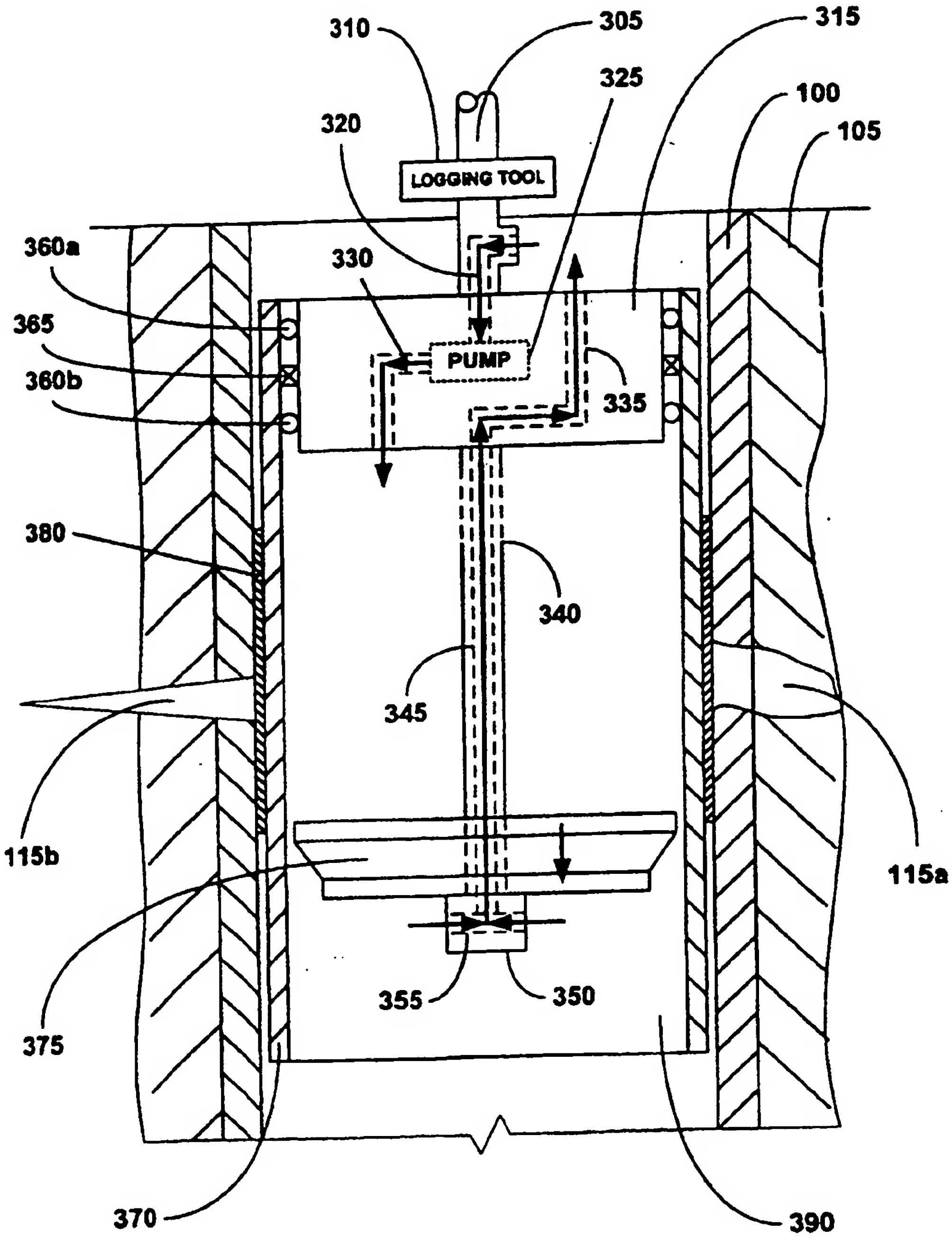

310
305
315
325
100
320
105
LOGGING TOOL
360a
330
365
PUMP
360b
335
380
340
345
115b
115a
375
355
350
370
390

FIGURE 3c

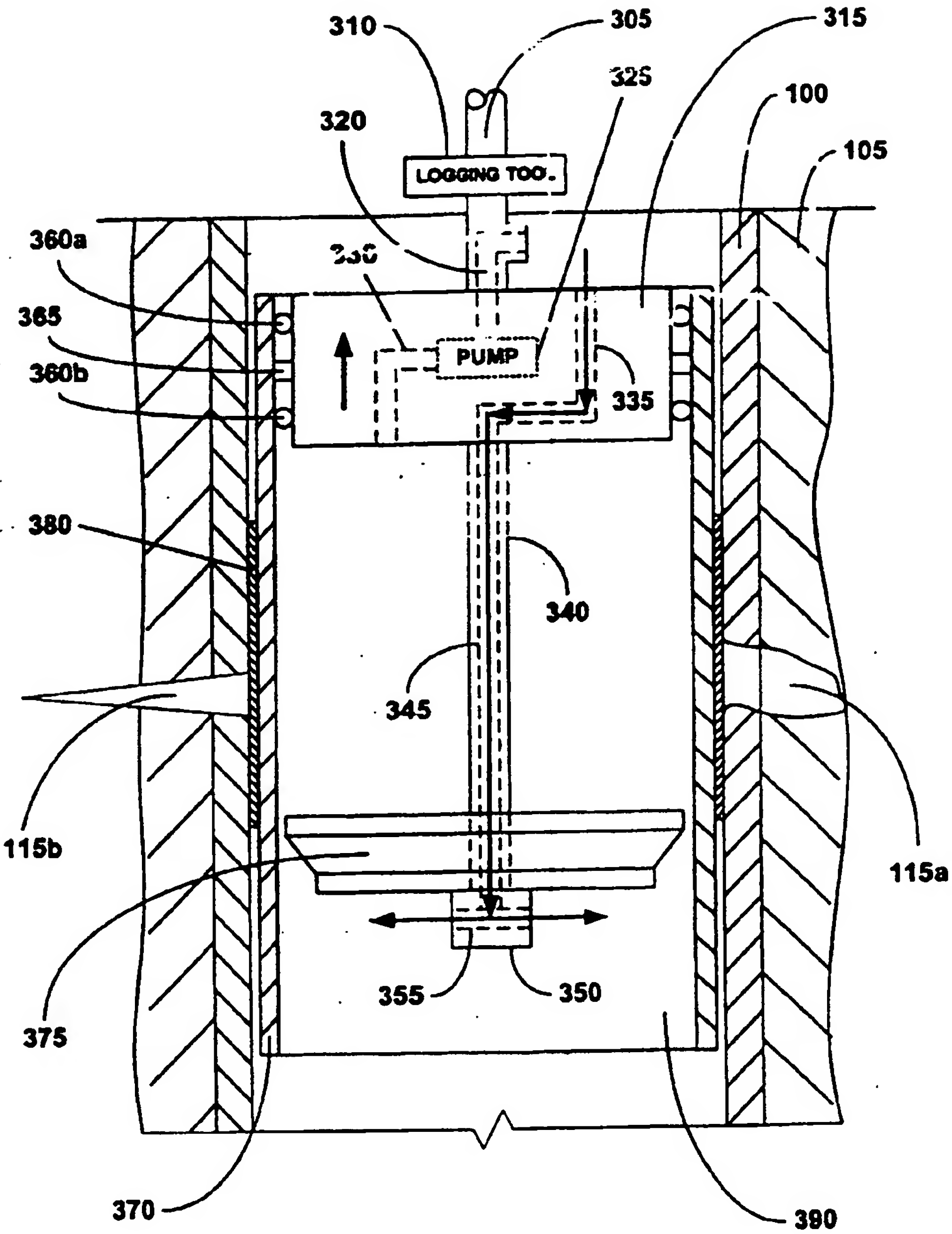

310
305
315
325
100
320
105
LOGGING TOO.
360a
330
365
PUMP
360b
335
380
340
345
115b
115a
375
355
350
370
390

FIGURE 3d

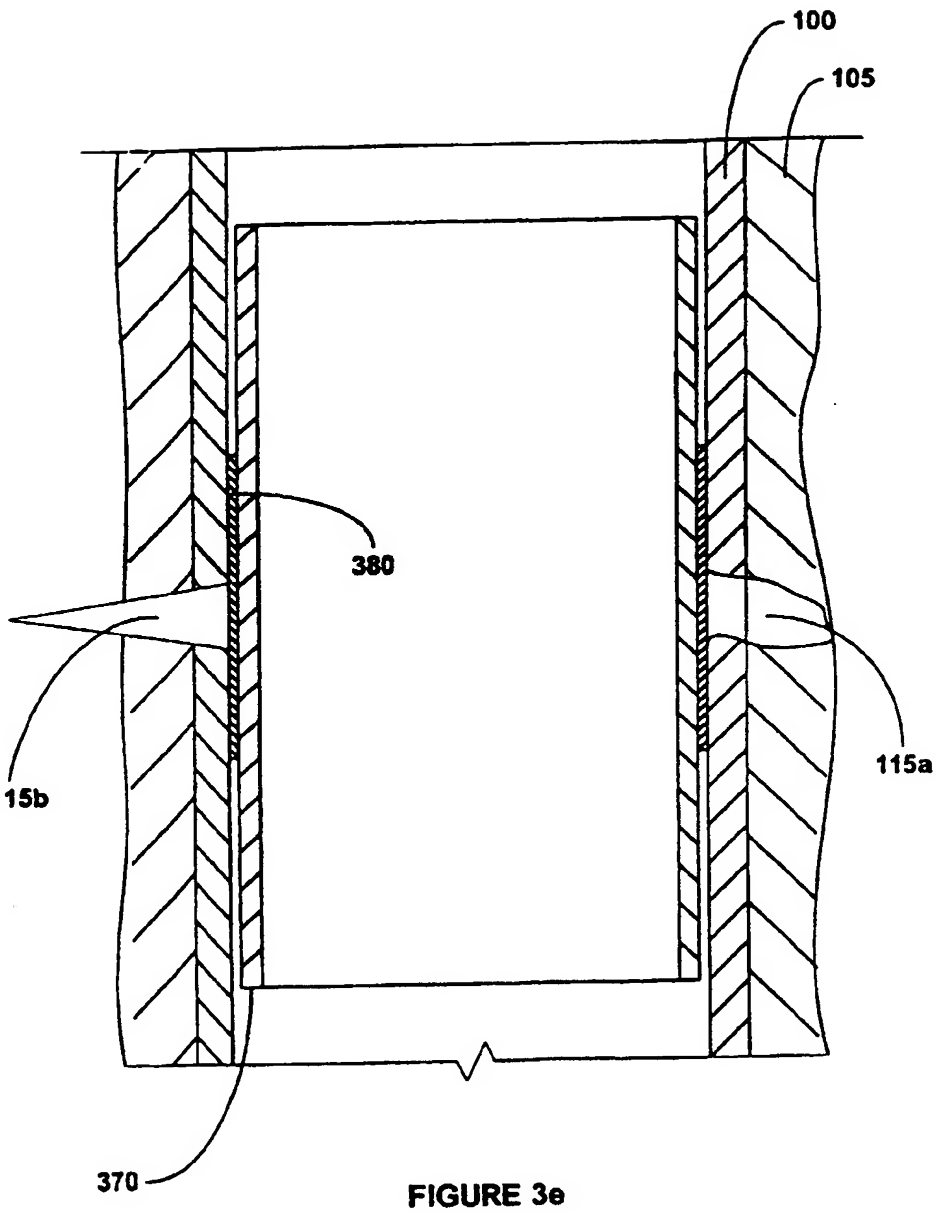
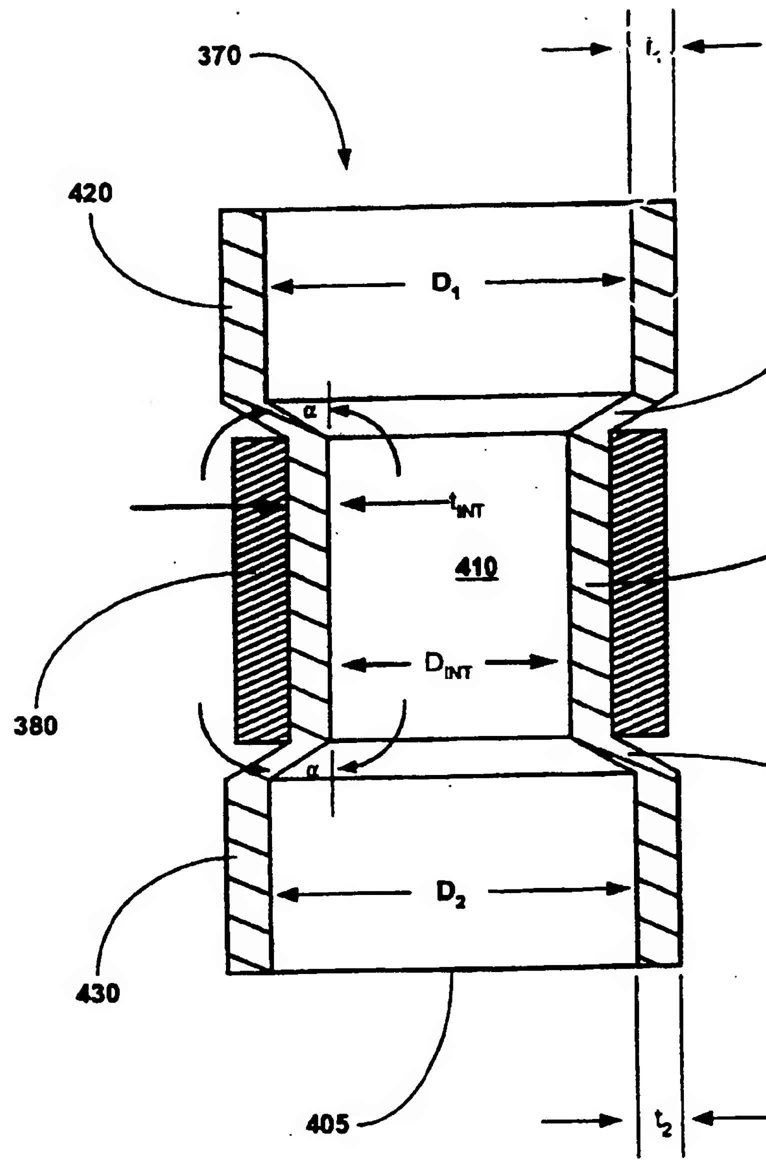


FIGURE 3e



370
t_1
420
D_1
435
α
425
t_{INT}
410
380
D_{INT}
α
440
D_2
430
405
t_2

FIGURE 4

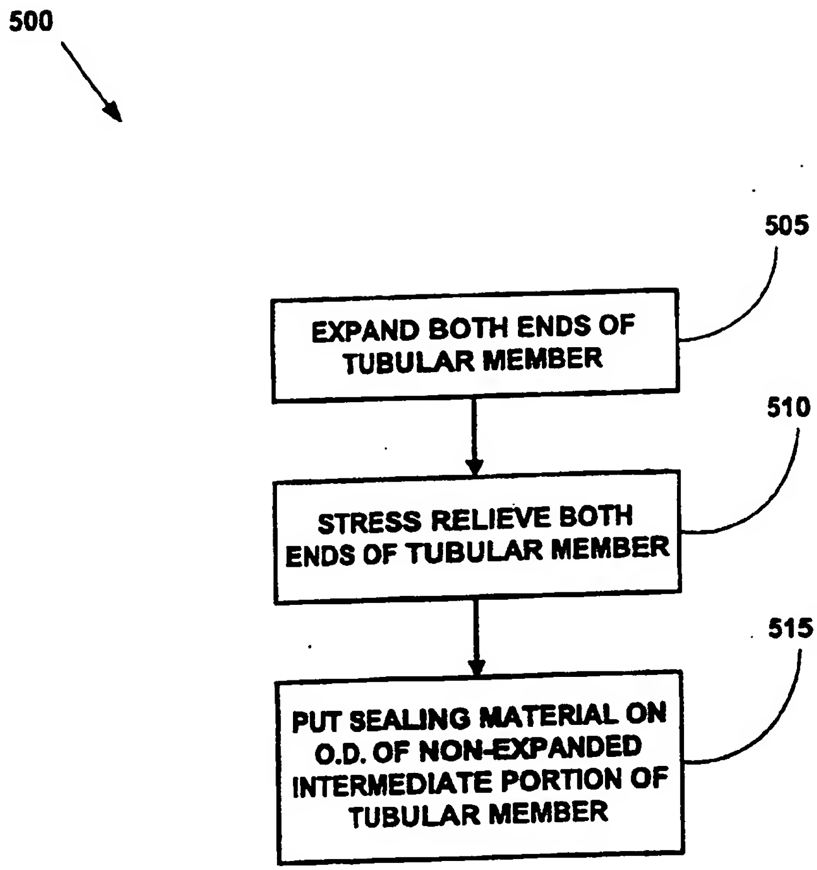

500
505
EXPAND BOTH ENDS OF TUBULAR MEMBER
510
STRESS RELIEVE BOTH ENDS OF TUBULAR MEMBER
515
PUT SEALING MATERIAL ON O.D. OF NON-EXPANDED INTERMEDIATE PORTION OF TUBULAR MEMBER

FIGURE 5

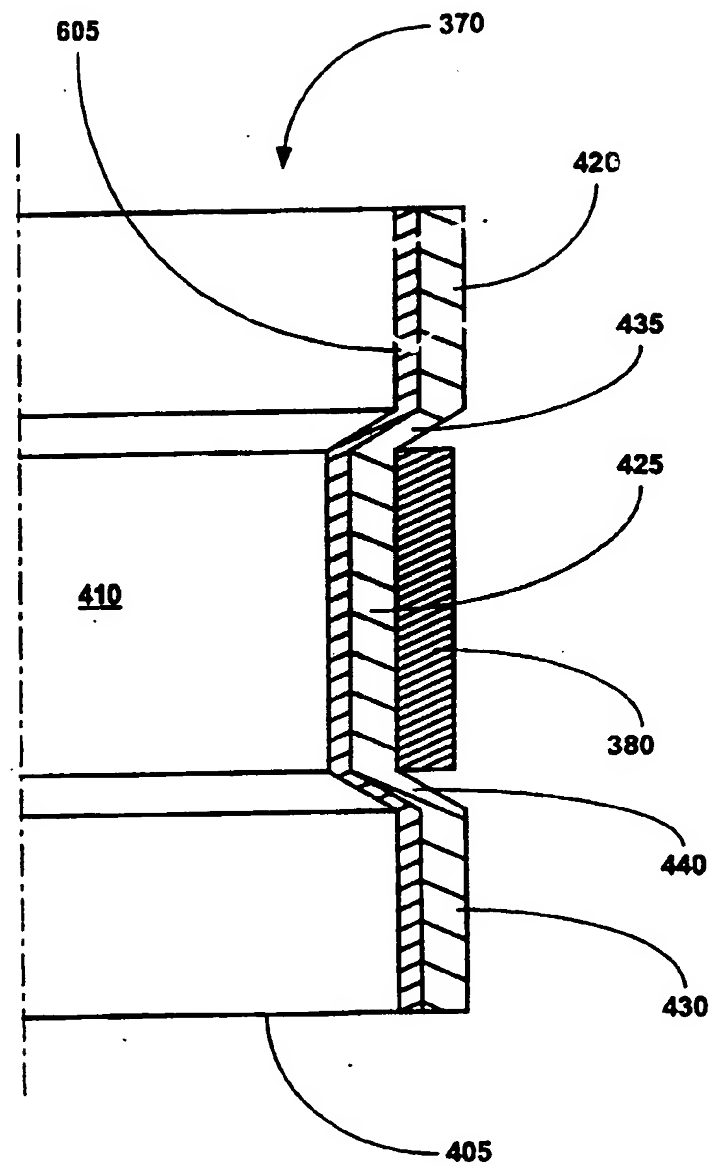


FIGURE 6

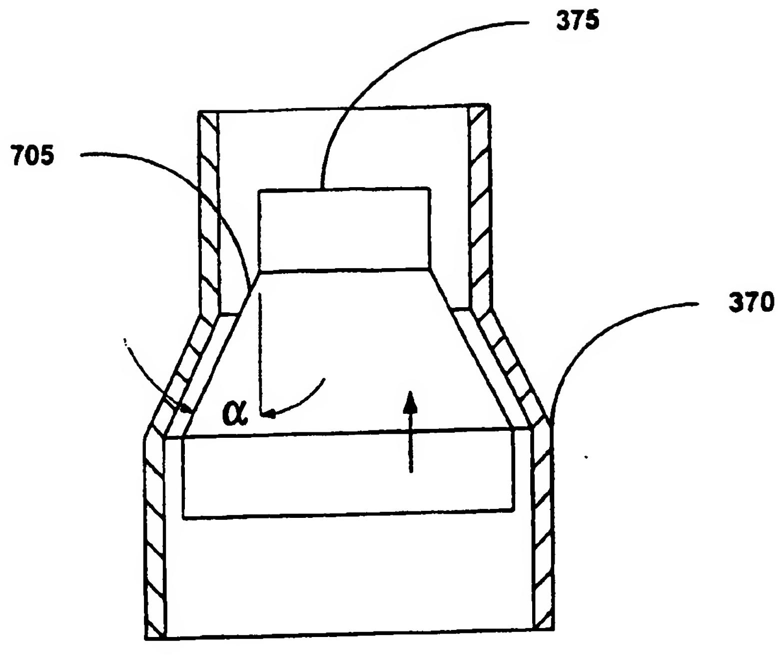


FIGURE 7

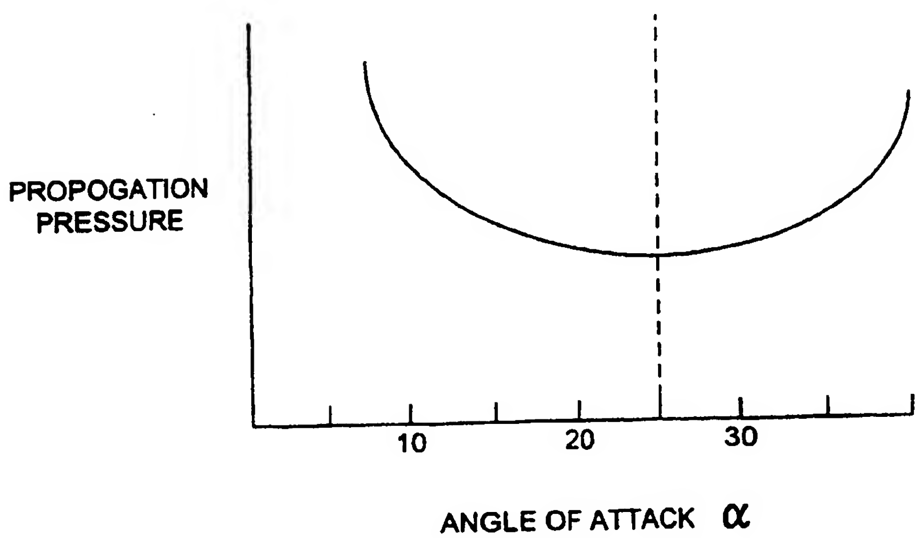


FIGURE 8

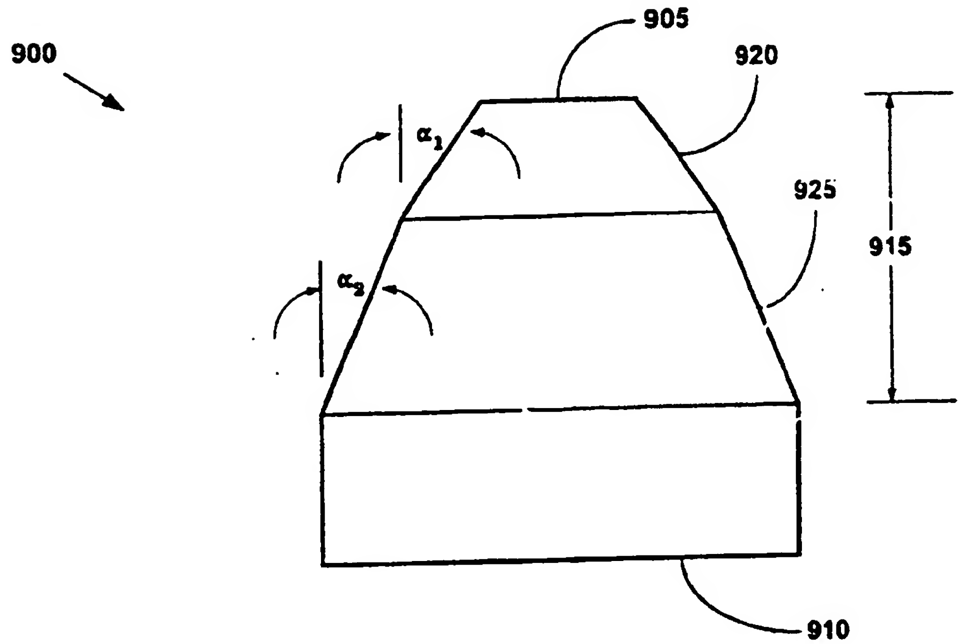


FIGURE 9

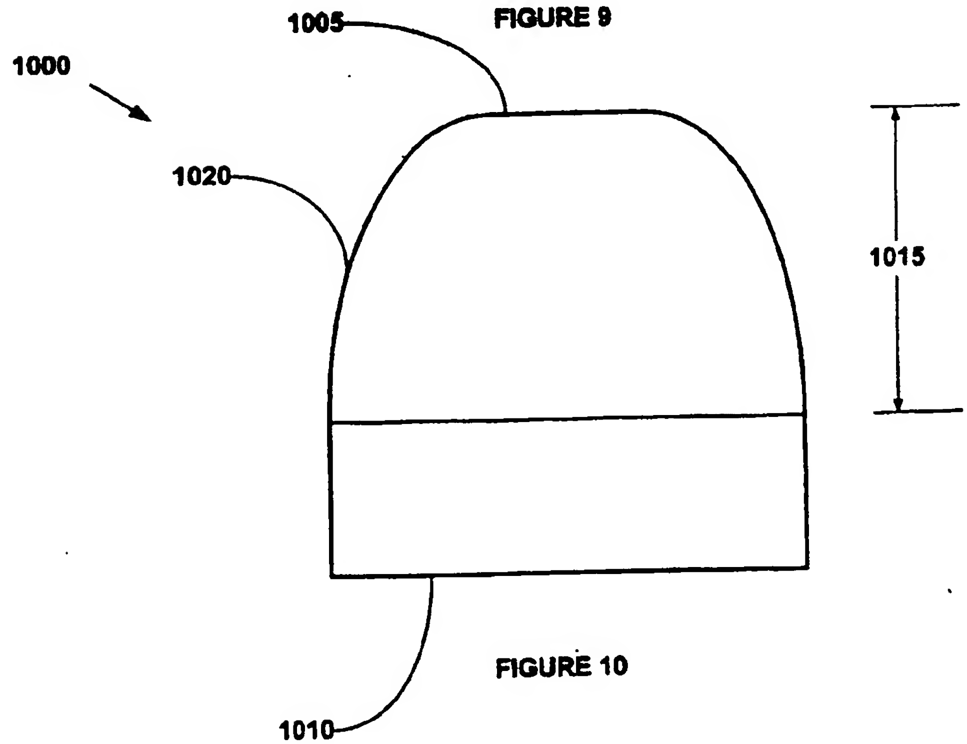


FIGURE 10

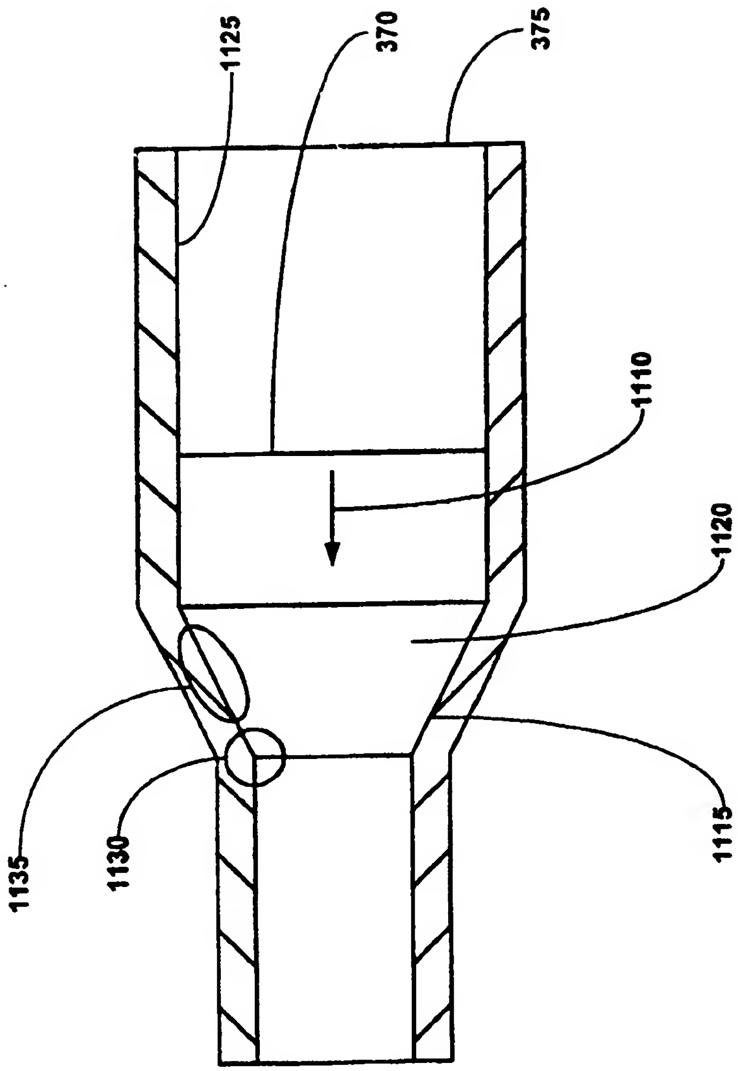


FIGURE 11

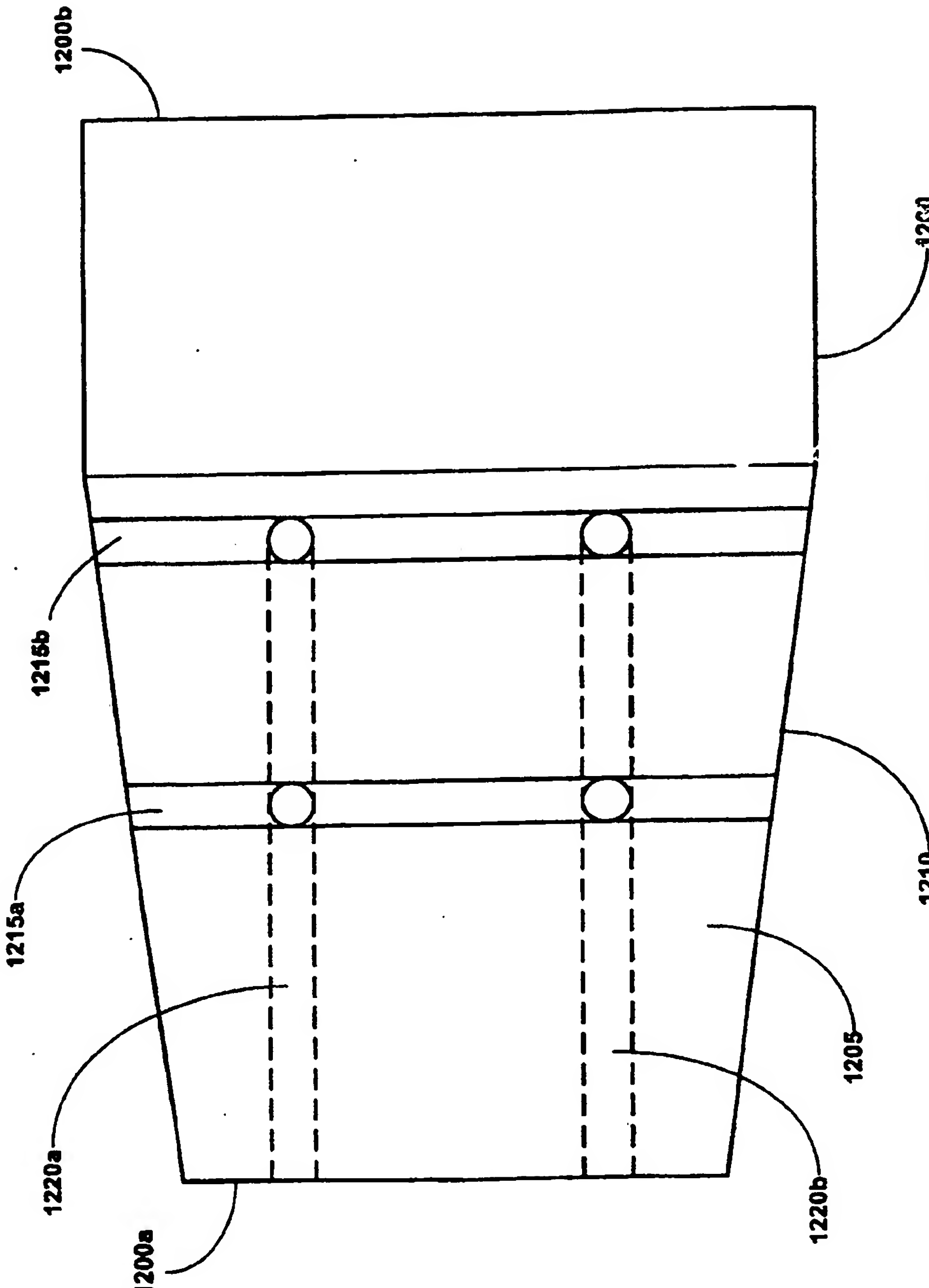


FIGURE 12

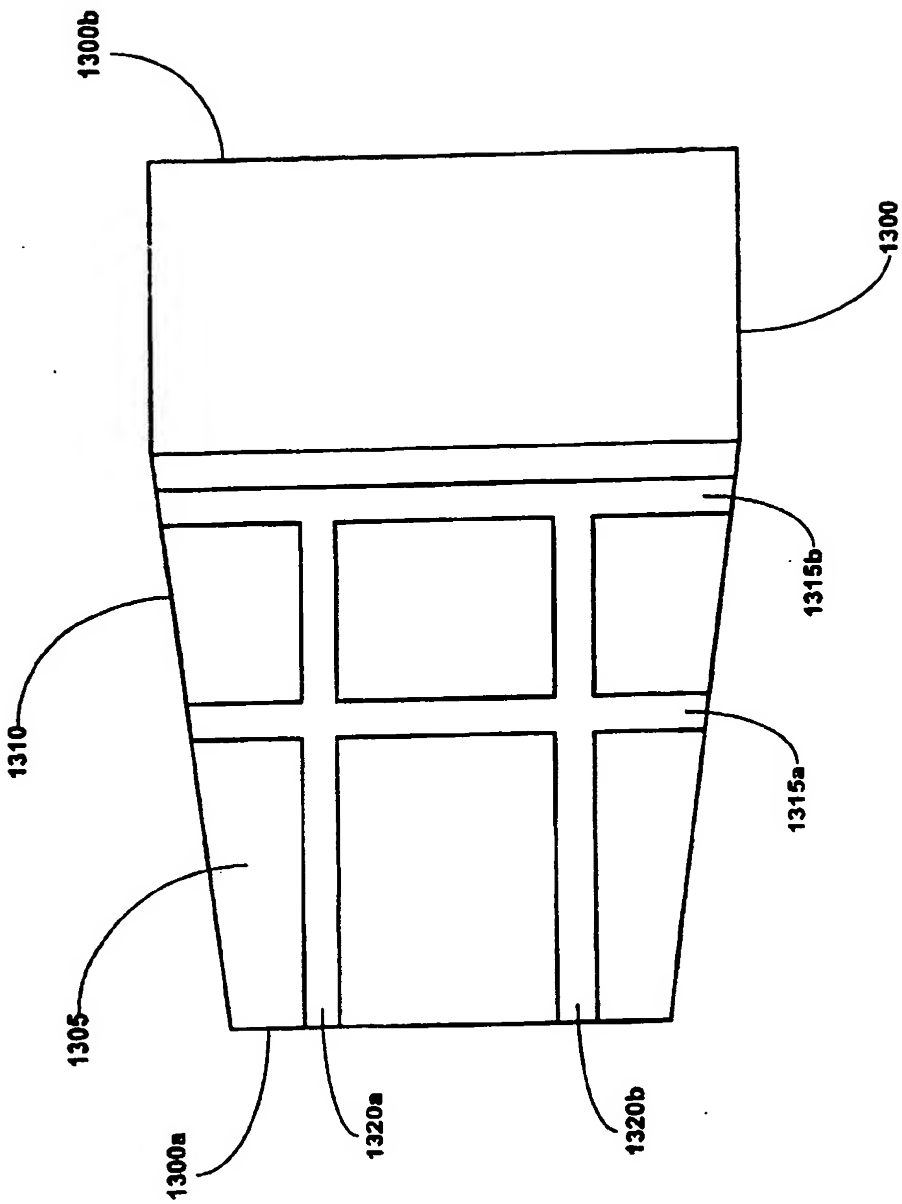


FIGURE 13

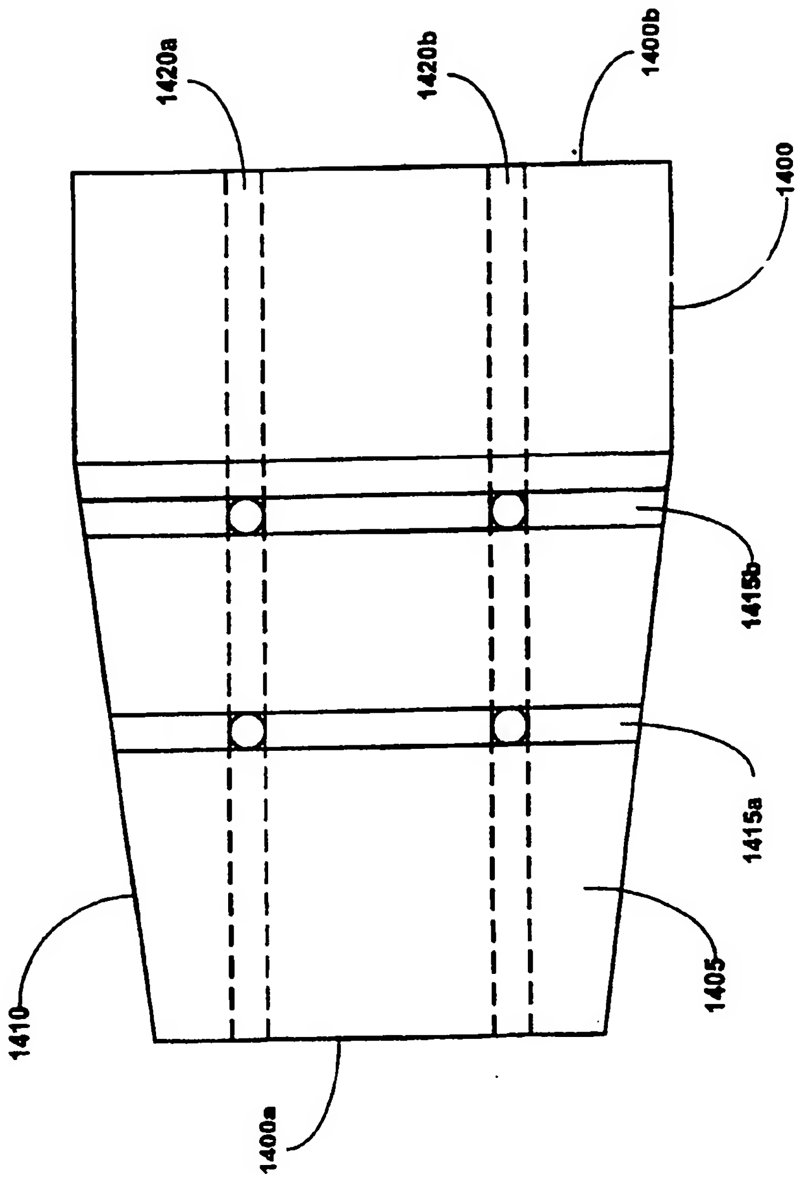


FIGURE 14

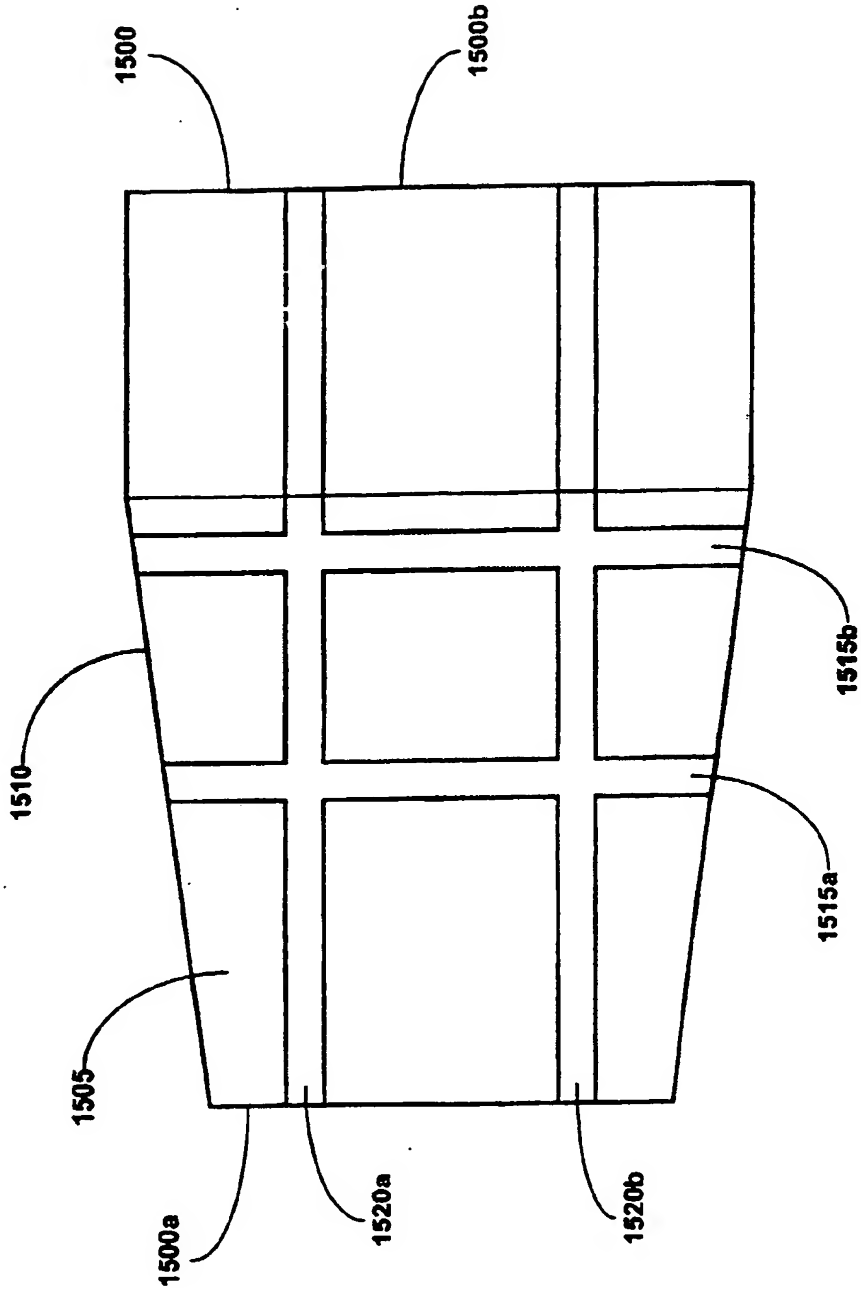


FIGURE 15

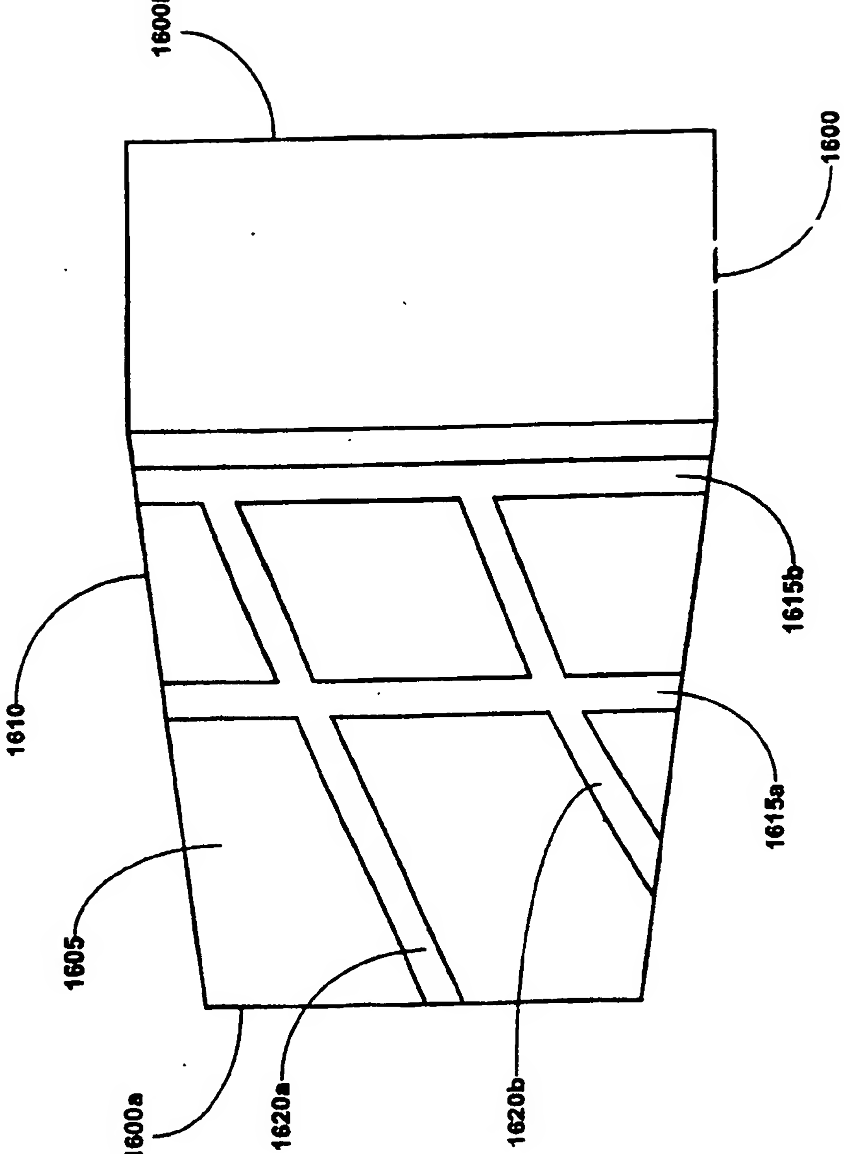


FIGURE 16

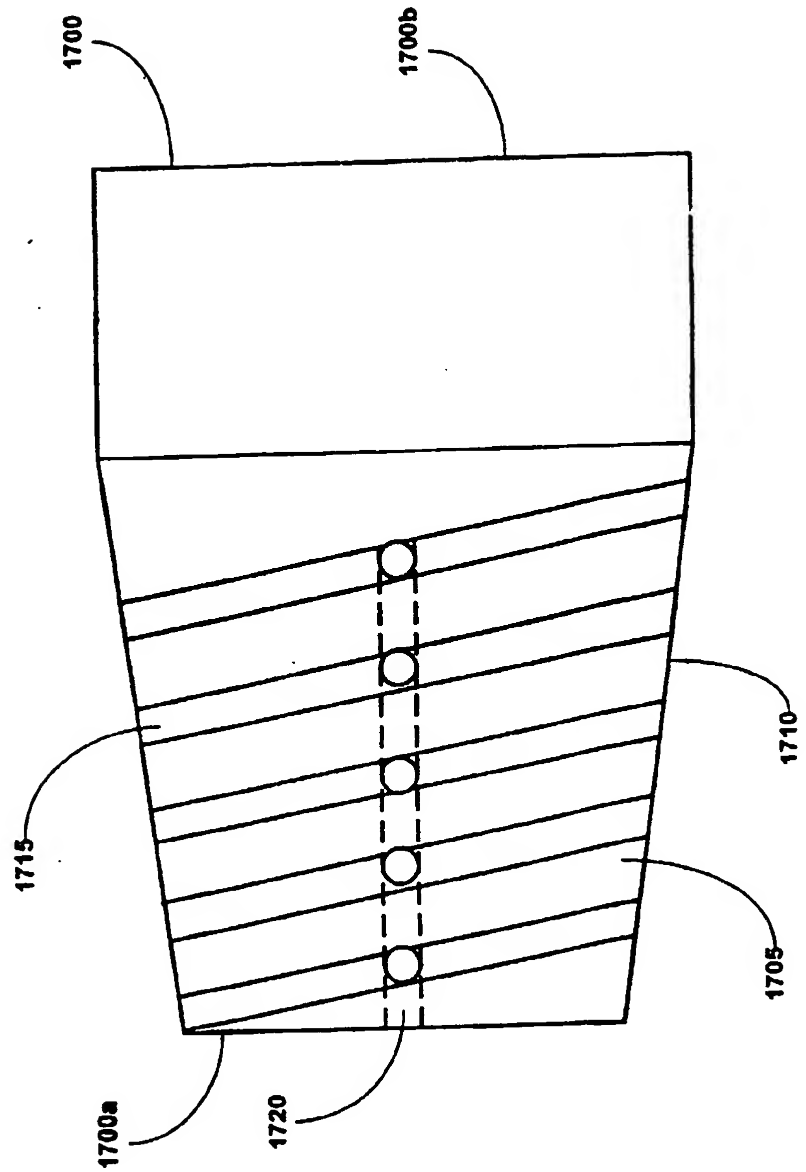


FIGURE 17

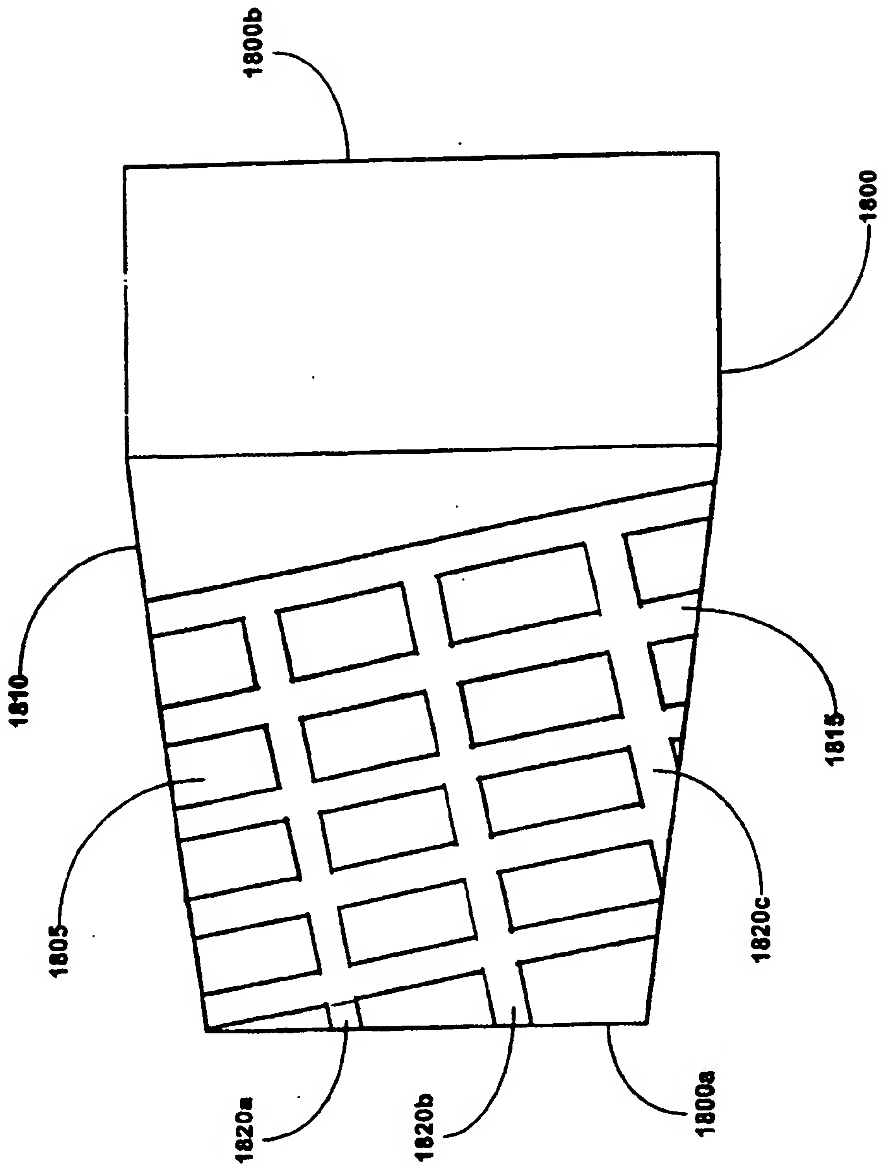


FIGURE 18

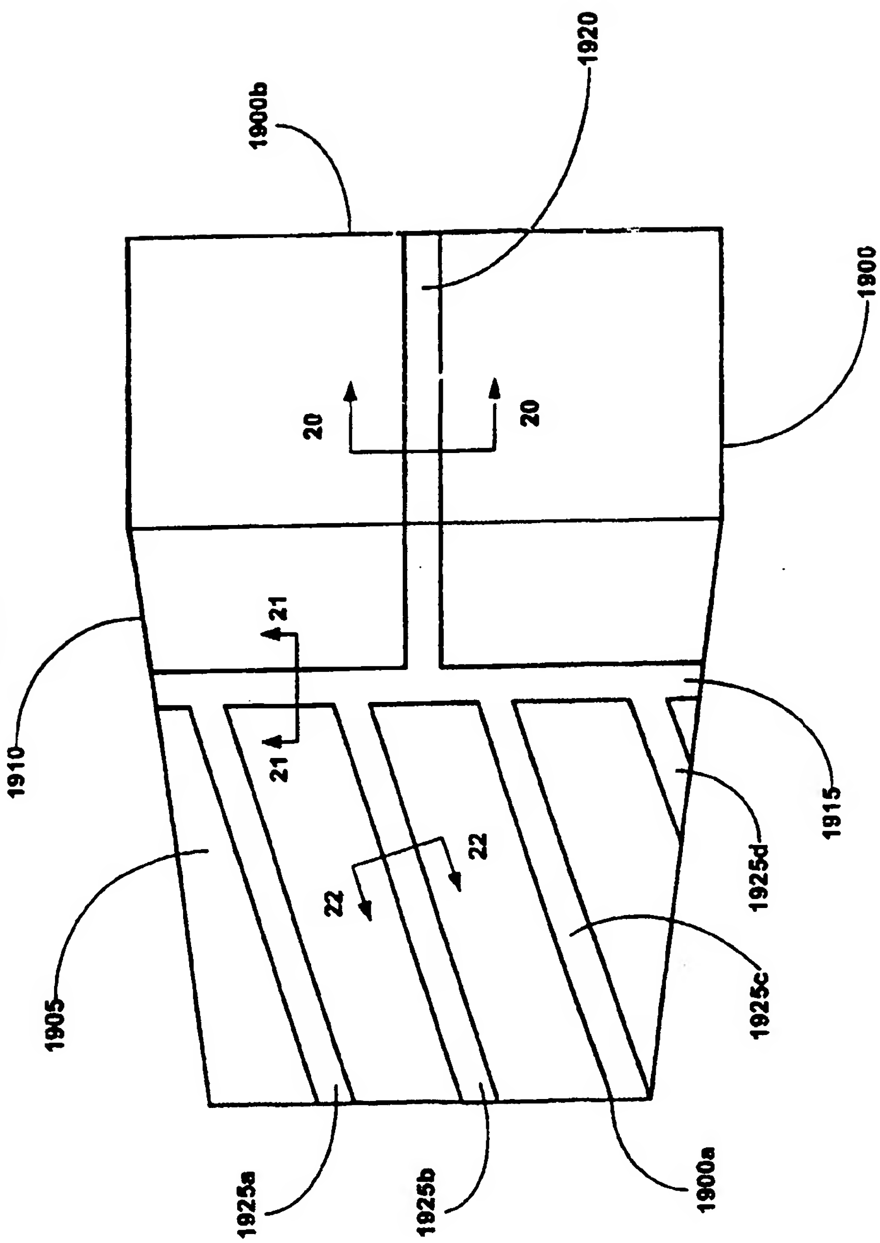


FIGURE 19

21/30

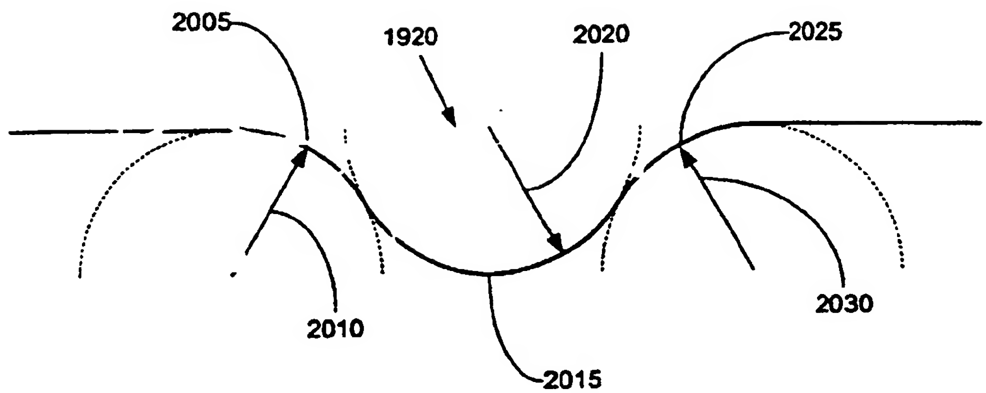


FIGURE 20

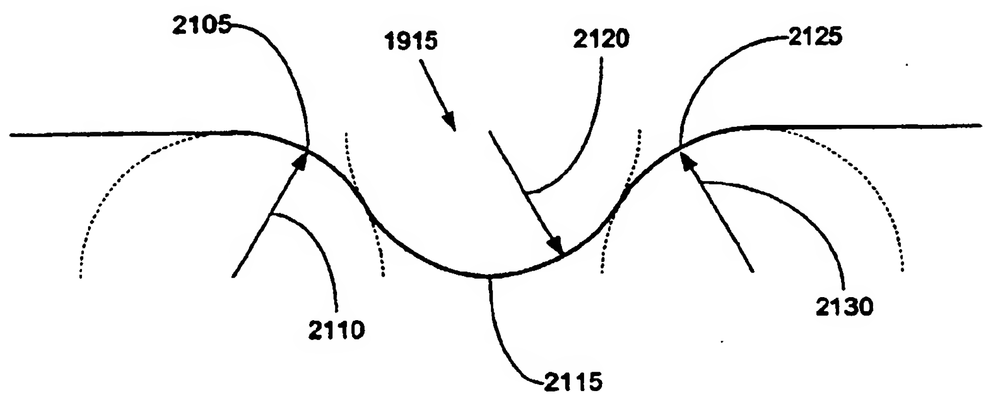


FIGURE 21

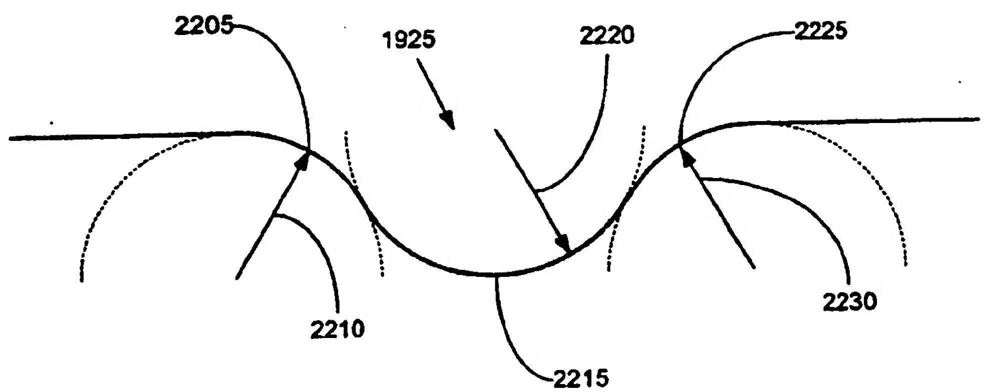


FIGURE 22

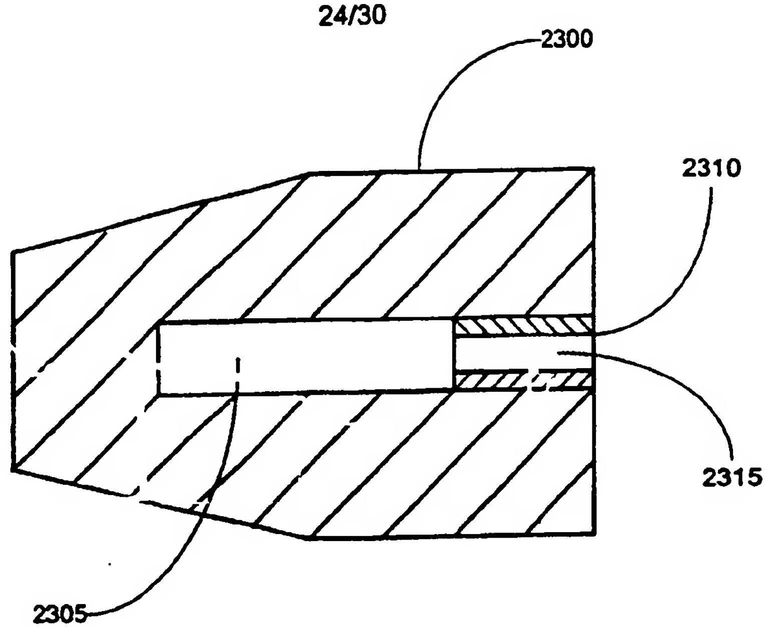


FIGURE 23

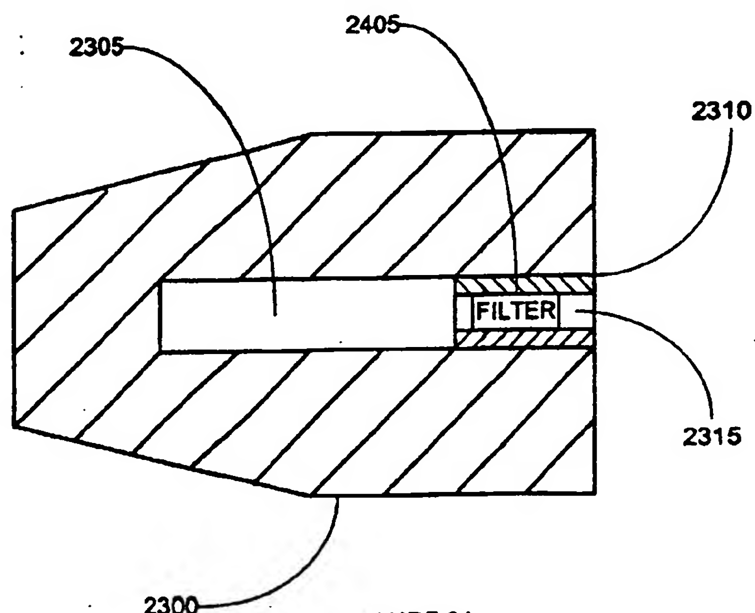


FIGURE 24

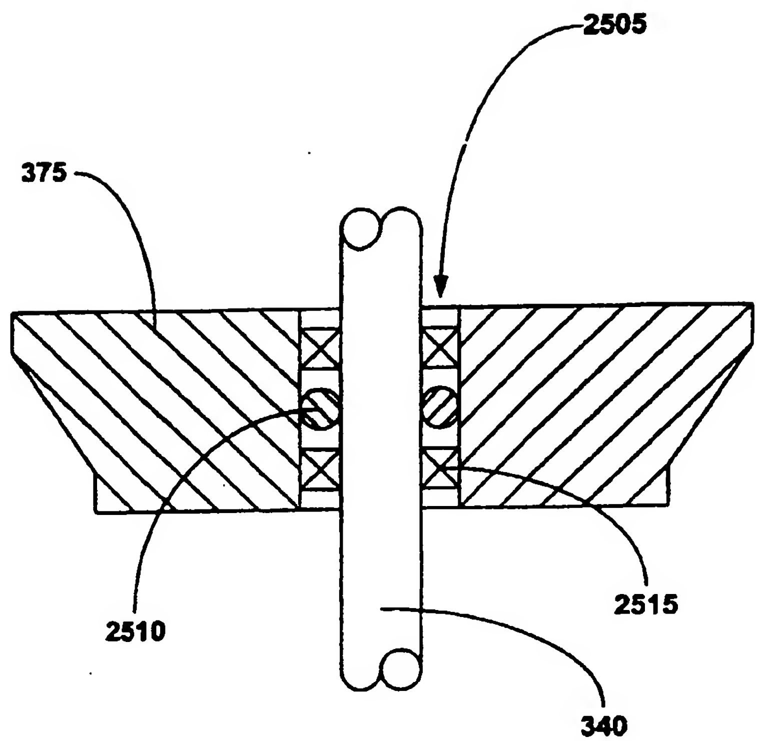


FIGURE 25

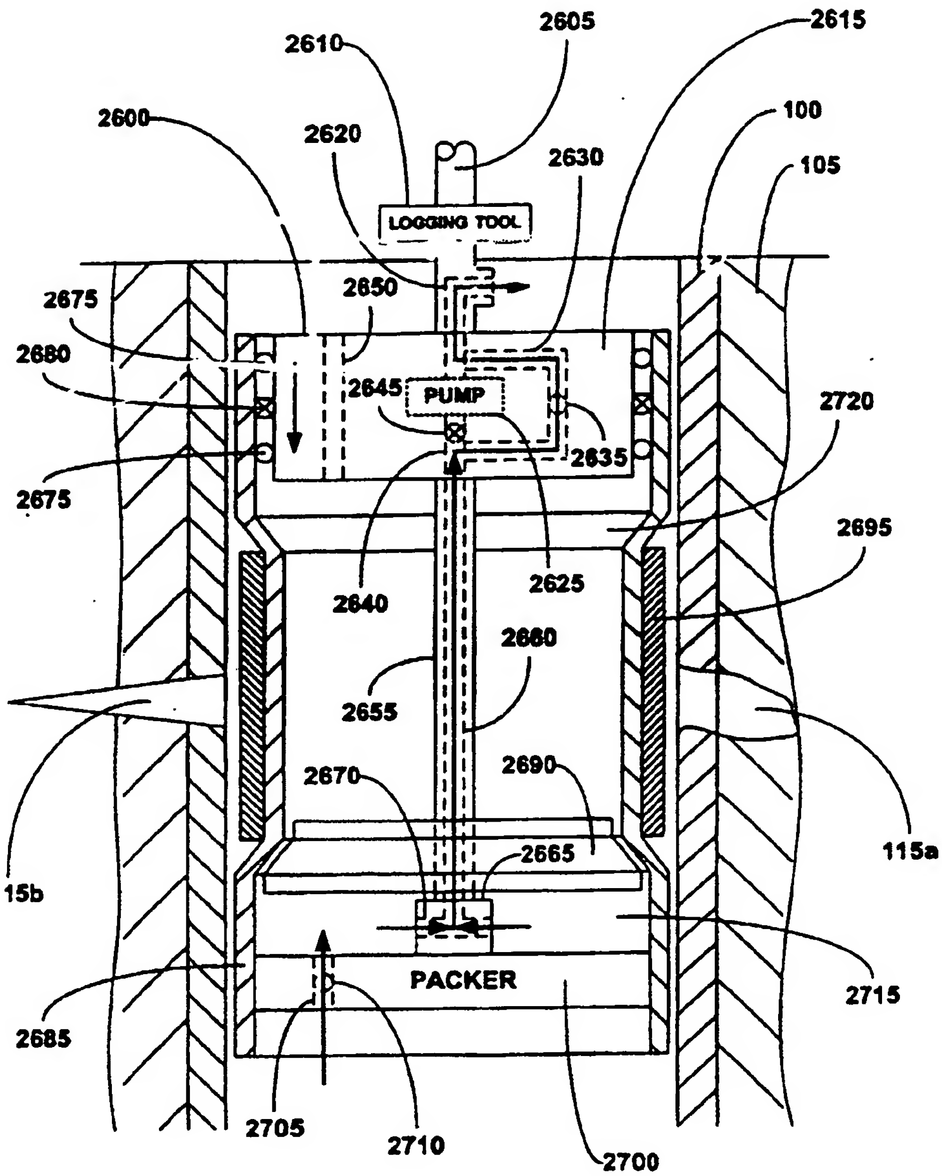

2605
2610
2615
2600
2620
100
2630
105
LOGGING TOOL
2675
2650
2680
2645
PUMP
2720
2635
2675
2695
2640
2625
2660
2655
2670
2690
115b
2665
115a
2715
PACKER
2685
2705
2710
2700

FIGURE 26a

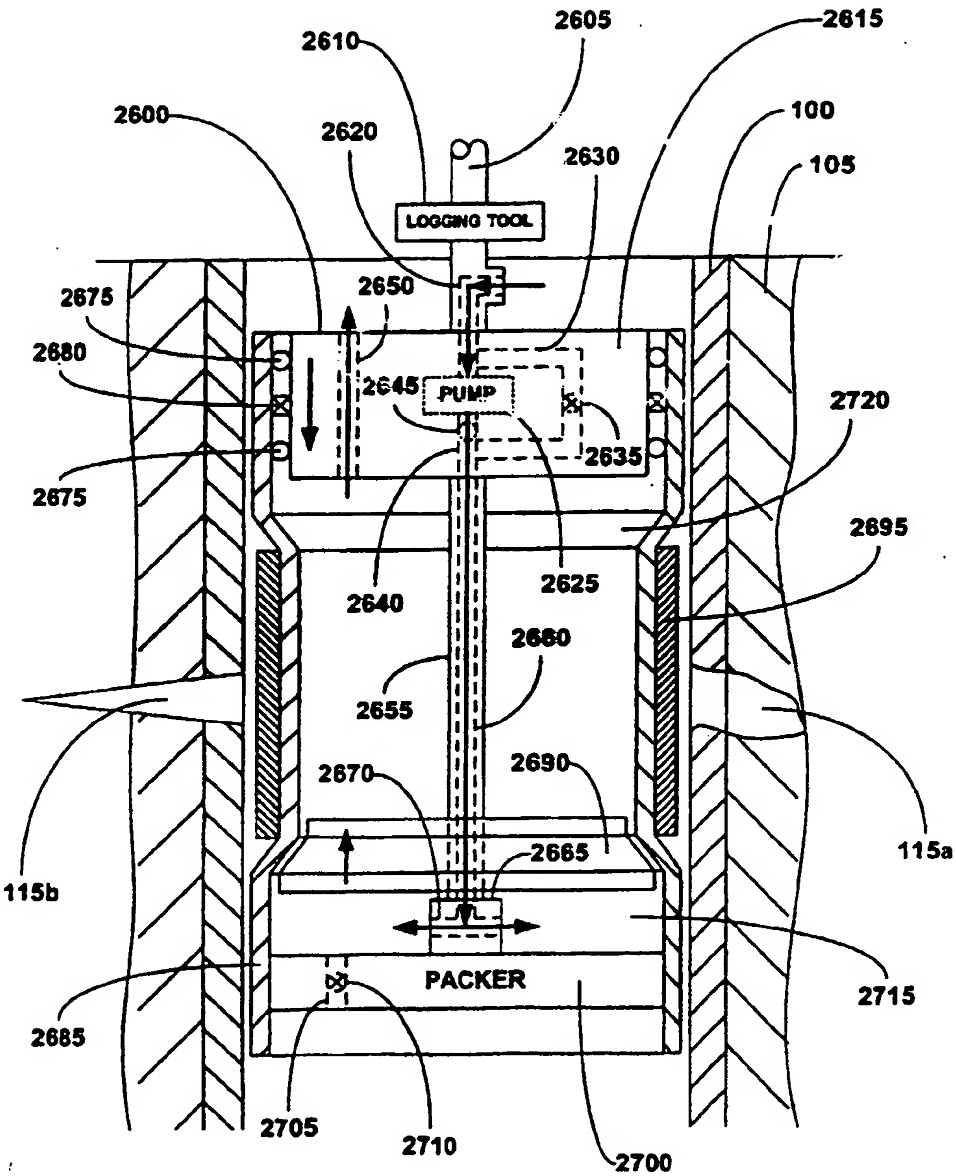

2610
2605
2615
2600
2620
2630
100
105
LOGGING TOOL
2675
2650
2680
2645
PUMP
2635
2675
2720
2695
2640
2625
2660
2655
2670
2690
2665
115b
115a
PACKER
2715
2685
2705
2710
2700

FIGURE 26b

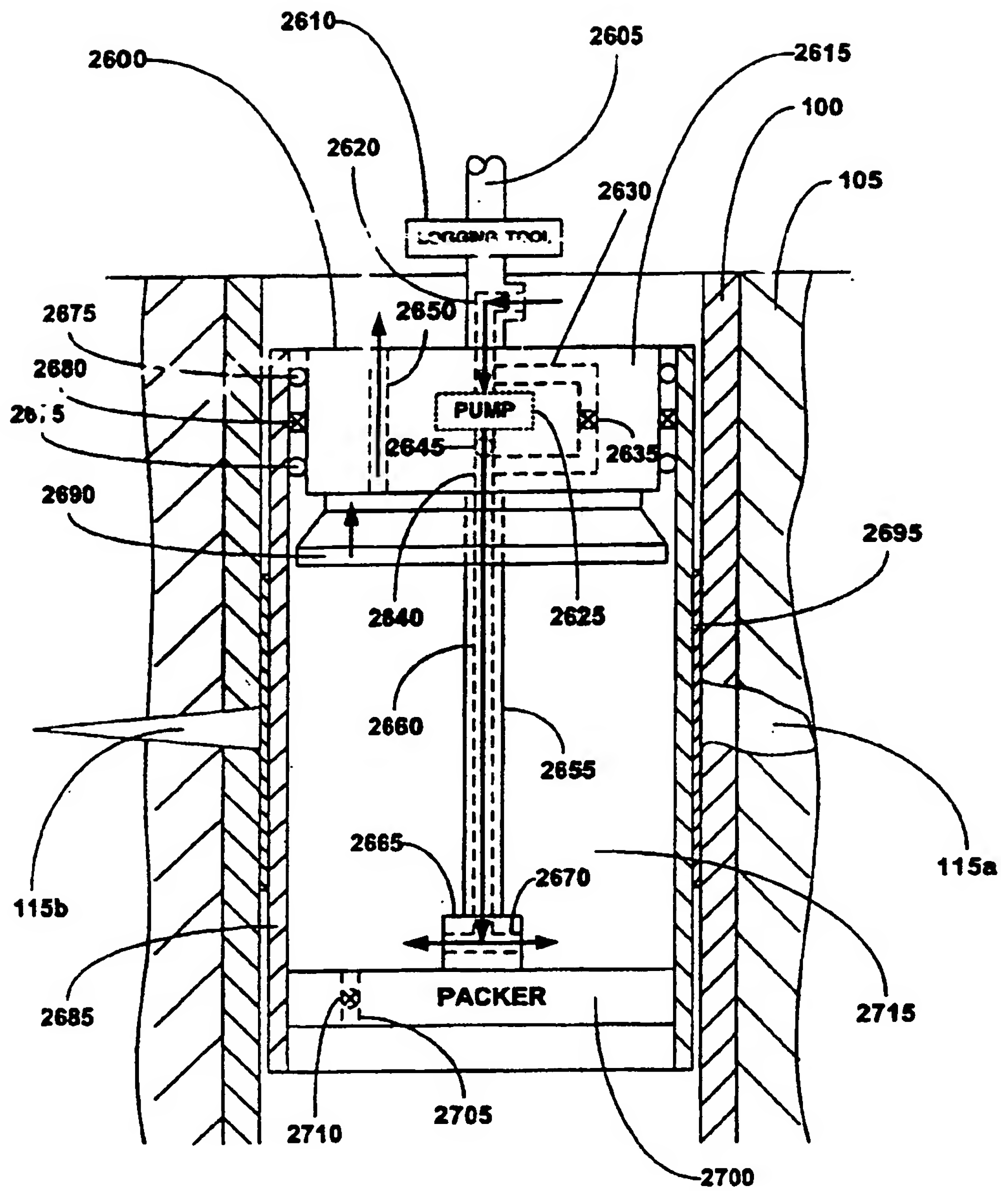

2610
2605
2600
2615
100
2620
105
2630
LOGGING TOOL
2675
2650
2680
PUMP
2645
2635
2690
2695
2640
2625
2660
2655
115b
115a
2665
2670
PACKER
2685
2715
2710
2705
2700

FIGURE 26c

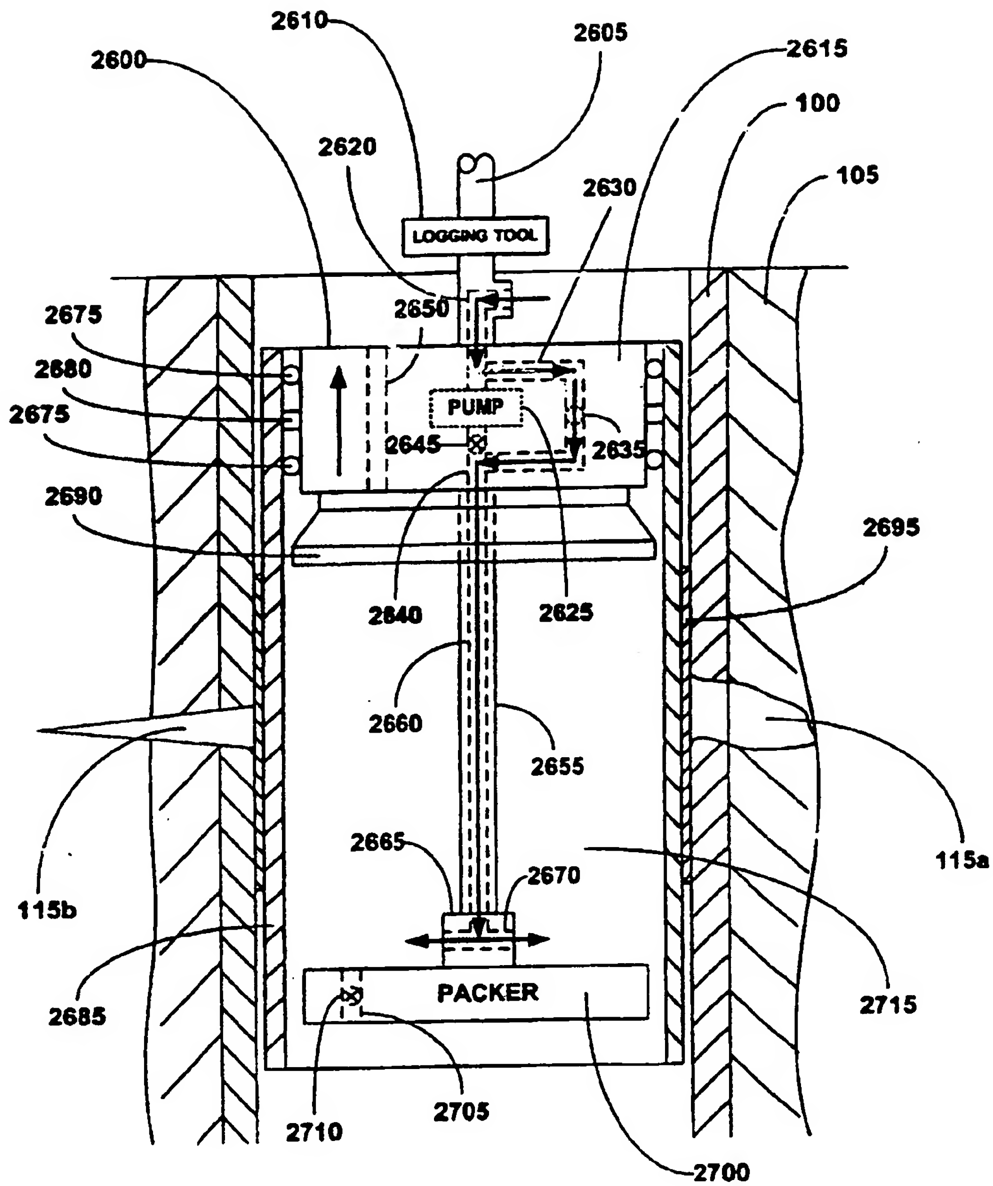

2610
2605
2600
2615
100
2620
105
2630
LOGGING TOOL
2650
2675
2680
PUMP
2675
2645
2635
2690
2695
2640
2625
2660
2655
115a
2665
2670
115b
2685
PACKER
2715
2705
2710
2700

FIGURE 26d

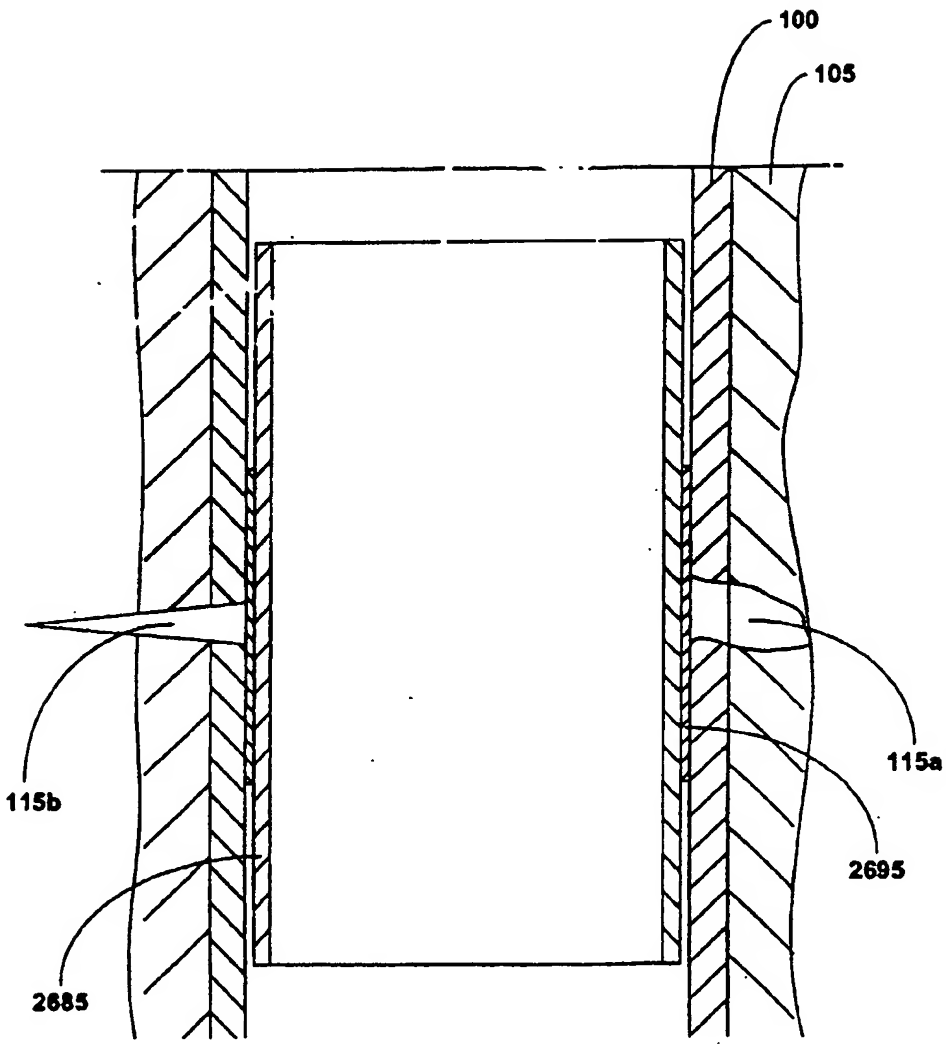


FIGURE 26e

2390628

WELLBORE CASING REPAIR

Background of the Invention

This invention relates generally to wellbore casing repair, and in particular to repair of a wellbore casing that is formed using expandable tubing.

Conventionally, when a wellbore is created, a number of casings are installed in the borehole to prevent collapse of the borehole wall and to prevent undesired outflow of drilling fluid into the formation or inflow of fluid from the formation into the borehole. The borehole is drilled in intervals whereby a casing which is to be installed in a lower borehole interval is lowered through a previously installed casing of an upper borehole interval. As a consequence of this procedure the casing of the lower interval is of smaller diameter than the casing of the upper interval. Thus, the casings are in a nested arrangement with casing diameters decreasing in downward direction. Cement annuli are provided between the outer surfaces of the casings and the borehole wall to seal the casings from the borehole wall. As a consequence of this nested arrangement a relatively large borehole diameter is required at the upper part of the wellbore. Such a large borehole diameter involves increased costs due to heavy casing handling equipment, large drill bits and increased volumes of drilling fluid and drill cuttings. Moreover, increased drilling rig time is involved due to required cement pumping, cement hardening, required equipment changes due to large variations in hole diameters drilled in the course of the well, and the large volume of cuttings drilled and removed.

Conventionally, when an opening is formed in the sidewalls of an existing wellbore casing, whether through damage to the casing or because of an intentional perforation of the casing to facilitate production or a fracturing operation, it is often necessary to seal off the opening in the existing wellbore casing. Conventional methods of sealing off such openings are expensive and unreliable.

The present invention is directed to overcoming one or more of the limitations of the existing procedures for forming and repairing wellbores.

(

Summary of the Invention

According to the present invention there is provided a method of coupling a first tubular member to a second tubular member, wherein the outside diameter of the first tubular member is less than the inside diameter of the second tubular member, comprising:

positioning at least a portion of the first tubular member within the second tubular member;

pressurizing a portion of the interior of the first tubular member by pumping fluidic materials proximate the first tubular member into the portion of the interior of the first tubular member;

displacing an expansion cone within the interior of the first tubular member; and

lubricating the interface between the first tubular member and the expansion cone.

Preferably, the second tubular member is selected from the group consisting of a wellbore casing, a pipeline, and a structural support.

Preferably, lubricating includes coating the first tubular member with a lubricant.

Preferably, lubricating includes injecting a lubricating fluid into the trailing edge of the interface between the first tubular member and the expansion cone.

Preferably, lubricating includes:

coating the first tubular member with a first component of a lubricant; and

circulating a second component of the lubricant into contact with the coating on the first tubular member.

Preferably, the method includes sealing off a portion of the first tubular member.

According to another aspect of the present invention there is provided an apparatus for coupling a first tubular member to a second tubular member, wherein the outside diameter of the first tubular member is less than the inside diameter of the second tubular member, comprising:

means for positioning at least a portion of the first tubular member within the second tubular member;

means for pressurizing a portion of the interior of the first tubular member by pumping fluidic materials proximate the first tubular member into the portion of the interior of the first tubular member;

means for displacing an expansion cone within the interior of the first tubular member; and

means for lubricating the interface between the first tubular member and the expansion cone.

Preferably, the second tubular member is selected from the group consisting of a wellbore casing, a pipeline, and a structural support.

Preferably, the apparatus further includes means for coating the first tubular member with a lubricant.

Preferably, the apparatus further includes means for injecting a lubricating fluid into the trailing edge of the interface between the first tubular member and the expansion cone.

Preferably, the apparatus further includes:

means for coating the first tubular member with a first component of a lubricant; and

means for circulating a second component of the lubricant into contact with the coating on the first tubular member.

Preferably, the apparatus further includes means for sealing off a portion of the first tubular member.

Preferably, the first tubular member includes a sealing member coupled to the outer surface of the first tubular member.

Preferably, the first tubular member includes:

a first end having a first outer diameter;

an intermediate portion coupled to the first end having an intermediate outer diameter; and

(

a second end having a second outer diameter, and coupled to the intermediate portion;

wherein the first and second outer diameters are greater than the intermediate outer diameter.

Preferably, the first end, second end, and intermediate portion of the first tubular member have wall thicknesses t_1, t_2 and t_{INT} and inside diameters D_1, D_2 and D_{INT}; and wherein the relationship between the wall thicknesses t_1, t_2 and t_{INT}, the inside diameters D_1, D_2 and D_{INT}, the inside diameter D_{TUBE} of the second tubular member that the first tubular member will be inserted into, and the outer diameter D_{cone} of the expansion cone is given by the following expression:

$$D_{TUBE} - 2 * t_1 \geq D_1 \geq \frac{1}{t_1}\left[(t_1 - t_{INT}) * D_{CONE} + t_{INT} * D_{INT}\right]$$

where $t_1 = t_2$; and

$D_1 = D_2$.

Preferably, the first tubular member includes:

a sealing member coupled to the outside surface of the intermediate portion.

Preferably, the first tubular member includes:

a first transition portion coupled to the first end and the intermediate portion inclined at a first angle; and

a second transition portion coupled to the second end and the intermediate portion inclined at a second angle;

wherein the first and second angles range from 5 to 45 degrees.

Preferably, the expansion cone includes an expansion cone surface having an angle of attack ranging from 10 to 40 degrees.

Preferably, the expansion cone includes:

a first expansion cone surface having a first angle of attack; and

a second expansion cone surface having a second angle of attack;

wherein the first angle of attack is greater than the second angle of attack.

Preferably, the expansion cone includes an expansion cone surface having a substantially parabolic profile.

Preferably, the expansion cone includes an inclined surface including one or more lubricating grooves.

Preferably, the expansion cone includes one or more internal lubricating passages coupled to each of one or more lubricating grooves.

Preferably, the first tubular member includes a sealing member coupled to the outer surface of the first tubular member.

Preferably, the first tubular member includes:

a first end having a first outer diameter;

an intermediate portion coupled to the first end having an intermediate outer diameter; and

a second end having a second outer diameter, and coupled to the intermediate portion;

wherein the first and second outer diameters are greater than the intermediate outer diameter.

Preferably, the first end, second end, and intermediate portion of the first tubular member have wall thicknesses t_1, t_2 and t_{INT} and inside diameters D_1, D_2 and D_{INT}; and wherein the relationship between the thicknesses t_1, t_2 and t_{INT}, the inside diameter D_1, D_2 and D_{INT}; the inside diameter D_{TUBE} of the second tubular member that the first tubular member will be inserted into, and the outside diameter D_{cone} of the expansion cone is given by the following expression:

$$D_{TUBE} - 2 * t_1 \geq D_1 \geq \frac{1}{t_1}\left[(t_1 - t_{INT}) * D_{CONE} + t_{INT} * D_{INT}\right]$$

where $t_1 = t_2$; and

$D_1 = D_2$.

Preferably, the first tubular member includes a sealing member coupled to the outside surface of the intermediate portion.

Preferably, the first tubular member includes:

a first transition portion coupled to the first end and the intermediate portion inclined at a first angle; and

a second transition portion coupled to the second end and the intermediate portion inclined at a second angle;

wherein the first and second angles range from 5 to 45 degrees.

Preferably, the expansion cone includes an expansion cone surface having an angle of attack ranging from 10 to 40 degrees.

Preferably, the expansion cone includes:

a first expansion cone surface having a first angle of attack; and

a second expansion cone surface having a second angle of attack;

wherein the first angle of attack is greater than the second angel of attack.

Preferably, the expansion cone includes an expansion cone surface having a substantially parabolic profile.

Preferably, the expansion cone includes an inclined surface including one or more lubricating grooves.

Preferably, the expansion cone includes one or more internal lubricating passages coupled to each of the lubricating grooves.

Brief Description of the Drawings

FIG. 1 is a fragmentary cross-sectional view of a wellbore casing including one or more openings.

FIG. 2 is a flow chart illustration of a method for repairing the wellbore casing of FIG. 1.

FIG. 3a is a fragmentary cross-sectional view of the placement of a repair apparatus within the wellbore casing of FIG. 1 wherein the expandable tubular member of the apparatus is positioned opposite the openings in the wellbore casing.

FIG. 3b is a fragmentary cross-sectional view of the radial expansion of the expandable tubular of the apparatus of FIG. 3a.

FIG. 3c is a fragmentary cross-sectional view of the completion of the radial expansion of the expandable tubular of the apparatus of FIG. 3b.

FIG. 3d is a fragmentary cross-sectional view of the removal of the repair apparatus from the repaired wellbore casing of FIG. 3c.

FIG. 3e is a fragmentary cross-sectional view of the repaired wellbore casing of FIG. 3d.

FIG. 4 is a cross-sectional illustration of the expandable tubular of the apparatus of FIG. 3a.

FIG. 5 is a flow chart illustration of a method for fabricating the expandable tubular of the apparatus of FIG. 3a.

FIG. 6 is a fragmentary cross-sectional illustration of the expandable tubular of FIG. 4.

FIG. 7 is a fragmentary cross-sectional illustration of an expansion cone expanding a tubular member.

FIG. 8 is a graphical illustration of the relationship between propagation pressure and the angle of attack of the expansion cone.

FIG. 9 is an illustration of an expansion cone optimally adapted to radially expand the expandable tubular member of FIG. 4.

FIG. 10 is an illustration of an expansion cone optimally adapted to radially expand the expandable tubular member of FIG. 4.

FIG. 11 is a fragmentary cross-sectional illustration of the lubrication of the interface between an expansion cone and a tubular member during the radial expansion process.

FIG. 12 is an illustration of an expansion cone including a system for lubricating the interface between the expansion cone and a tubular member during the radial expansion of the tubular member.

FIG. 13 is an illustration of an expansion cone including a system for lubricating the interface between the expansion cone and a tubular member during the radial expansion of the tubular member.

FIG. 14 is an illustration of an expansion cone including a system for lubricating the interface between the expansion cone and a tubular member during the radial expansion of the tubular member.

FIG. 15 is an illustration of an expansion cone including a system for lubricating the interface between the expansion cone and a tubular member during the radial expansion of the tubular member.

FIG. 16 is an illustration of an expansion cone including a system for lubricating the interface between the expansion cone and a tubular member during the radial expansion of the tubular member.

FIG. 17 is an illustration of an expansion cone including a system for lubricating the interface between the expansion cone and a tubular member during the radial expansion of the tubular member.

FIG. 18 is an illustration of an expansion cone including a system for lubricating the interface between the expansion cone and a tubular member during the radial expansion of the tubular member.

FIG. 19 is an illustration of an expansion cone including a system for lubricating the interface between the expansion cone and a tubular member during the radial expansion of the tubular member.

FIG. 20 is a cross-sectional illustration of the first axial groove of the expansion cone of FIG. 19.

FIG. 21 is a cross-sectional illustration of the circumferential groove of the expansion cone of FIG. 19.

FIG. 22 is a cross-sectional illustration of one of the second axial grooves of the expansion cone of FIG. 19.

FIG. 23 is a cross sectional illustration of an expansion cone including internal flow passages having inserts for adjusting the flow of lubricant fluids.

FIG. 24 is a cross sectional illustration of the expansion cone of FIG. 23 further including an insert having a filter for filtering out foreign materials from the lubricant fluids.

FIG. 25 is a fragmentary cross sectional illustration of the expansion cone of the repair apparatus of FIG. 3a.

FIG. 26a is a fragmentary cross-sectional view of the placement of a repair apparatus within the wellbore casing of FIG. 1 wherein the expandable tubular member of the apparatus is positioned opposite the openings in the wellbore casing.

FIG. 26b is a fragmentary cross-sectional view of the radial expansion of the expandable tubular of the apparatus of FIG. 26a.

FIG. 26c is a fragmentary cross-sectional view of the completion of the radial expansion of the expandable tubular of the apparatus of FIG. 26b.

FIG. 26d is a fragmentary cross-sectional view of the removal of the repair apparatus from the repaired wellbore casing of FIG. 26c.

FIG. 26e is a fragmentary cross-sectional view of the repaired wellbore casing of FIG. 26d.

Detailed Description

Referring initially to FIG. 1, a wellbore casing 100 having an outer annular layer 105 of a sealing material is positioned within a subterranean formation 110. The wellbore casing 100 may be positioned in any orientation from vertical to horizontal. The wellbore casing 100 further includes one or more openings 115a and 115b. The openings 115 may, for example, be the result of: defects in the wellbore casing 100, intentional perforations of the casing to facilitate production, thin walled sections of casing caused by drilling and/or wireline wear, or fracturing operations. As will be recognized by persons having ordinary skill in the art, such openings 115 in a wellbore 100 can seriously adversely impact the subsequent production of oil and gas from the subterranean formation 110 unless they are sealed off. More generally, the wellbore casing 115 may include thin walled sections that need cladding in order to prevent a catastrophic failure.

Referring to FIG. 2, a method 200 for repairing a defect in a wellbore casing using a repair apparatus having a logging tool, a pump, an expansion cone, and an expandable tubular member includes the steps of: (1) positioning the repair apparatus within the wellbore casing in step 205; (2) locating the defect in the wellbore casing using the logging tool of the repair apparatus in step 210; (3) positioning the expandable tubular member in opposition to the defect in the wellbore casing in step 215; and (4) radially expanding the expandable tubular member into intimate contact with the wellbore casing by pressurizing a portion of the expandable tubular member using the pump and extruding the expandable tubular member off of the expansion cone in step 220. In this manner, defects in a

wellbore casing are repaired by a compact and self-contained repair apparatus that is positioned downhole. More generally, the repair apparatus is used to repair defects in wellbore casings, pipelines, and structural supports.

As illustrated in FIG. 3a, in step 205, a repair apparatus 300 is positioned within the wellbore casing 100.

The repair apparatus 300 includes a first support member 305, a logging tool 310, a housing 315, a first fluid conduit 320, a pump 325, a second fluid conduit 330, a third fluid conduit 335, a second support member 340, a fourth fluid conduit 345, a third support member 350, a fifth fluid conduit 355, sealing members 360, a locking member 365, an expandable tubular 370, an expansion cone 375, and a sealing member 380.

The first support member 305 is preferably coupled to the logging tool 310 and the housing 315. The first support member 305 is preferably adapted to be coupled to and supported by a conventional support member such as, for example, a wireline, coiled tubing, or a drill string. The first support member 305 preferably has a substantially annular cross section in order to provide one or more conduits for conveying fluidic materials from the repair apparatus 300. The first support member 305 is further preferably adapted to convey electrical power and communication signals to the logging tool 310, the pump 325, and the locking member 365.

The logging tool 310 is preferably coupled to the first support member 305. The logging tool 310 is preferably adapted to detect defects in the wellbore casing 100. The logging tool 310 may be any number of conventional commercially available logging tools suitable for detecting defects in wellbore casings, pipelines, or structural supports. The logging tool 310 is a CAST logging tool, available from Halliburton(RTM) Energy Services in order to optimally provide detection of defects in the wellbore casing 100. The logging tool 310 is contained within the housing 315 in order to provide an repair apparatus 300 that is rugged and compact.

The housing 315 is preferably coupled to the first support member 305, the second support member 340, the sealing members 360, and the locking member 365. The housing 315 is preferably releasably coupled to the tubular member 370. The

housing 315 is further preferably adapted to contain and/or support the logging tool 310 and the pump 325.

The first fluid conduit 320 is preferably fluidicly coupled to the inlet of the pump 325 and the exterior region above the housing 315. The first fluid conduit 320 may be contained within the first support member 305 and the housing 315. The first fluid conduit 320 is preferably adapted to convey fluidic materials such as, for example, drilling muds, water, and lubricants at operating pressures and flow rates ranging from about 0 to 12,000 psi and 0 to 500 gallons/minute in order to optimally propagate the expansion cone 375.

The pump 325 is fluidicly coupled to the first fluid conduit 320 and the second fluid conduit 330. The pump 325 is further preferably contained within and supported by the housing 315. Alternatively, the pump 325 may be positioned above the housing 315. The pump 325 is preferably adapted to convey fluidic materials from the first fluid conduit 320 to the second fluid conduit 330 at operating pressures and flow rates ranging from about 0 to 12,000 psi and 0 to 500 gallons/minute in order to optimally provide the operating pressure for propagating the expansion cone 375. The pump 325 may be any number of conventional commercially available pumps. The pump 325 is a flow control pump out section for dirty fluids, available from Halliburton(RTM) Energy Services in order to optimally provide the operating pressures and flow rates for propagating the expansion cone 375. The pump 325 is preferably adapted to pressurize an interior portion 385 of the expandable tubular member 370 to operating pressures ranging from about 0 to 12,000 psi.

The second fluid conduit 330 is fluidicly coupled to the outlet of the pump 325 and the interior portion 385 of the expandable tubular member 370. The second fluid conduit 330 is further preferably contained within the housing 315. The second fluid conduit 330 is preferably adapted to convey fluidic materials such as, for example, drilling muds, water, and lubricants at operating pressures and flow rates ranging from about 0 to 12,000 psi and 0 to 500 gallons/minute in order to optimally propagate the expansion cone 375.

The third fluid conduit 335 is fluidicly coupled to the exterior region above the housing 315 and the interior portion 385 of the expandable tubular member 370. The third fluid conduit 335 is further preferably contained within the housing 315. The third fluid conduit 330 is preferably adapted to convey fluidic materials such as, for example, drilling muds, water, and lubricants at operating pressures and flow rates ranging from about 0 to 12,000 psi and 0 to 500 gallons/minute in order to optimally propagate the expansion cone 375.

The second support member 340 is coupled to the housing 315 and the third support member 350. The second support member 340 is further preferably movably and sealingly coupled to the expansion cone 375. The second support member 340 preferably has a substantially annular cross section in order to provide one or more conduits for conveying fluidic materials. The second support member 340 is centrally positioned within the expandable tubular member 370.

The fourth fluid conduit 345 is fluidicly coupled to the third fluid conduit 335 and the fifth fluid conduit 355. The fourth fluid conduit 345 is further preferably contained within the second support member 340. The fourth fluid conduit 345 is preferably adapted to convey fluidic materials such as, for example, drilling muds, water, and lubricants at operating pressures and flow rates ranging from about 0 to 12,000 psi and 0 to 500 gallons/minute in order to optimally propagate the expansion cone 375.

The third support member 350 is coupled to the second support member 340. The third support member 350 is further preferably adapted to support the expansion cone 375. The third support member 350 preferably has a substantially annular cross section in order to provide one or more conduits for conveying fluidic materials.

The fifth fluid conduit 355 is fluidicly coupled to the fourth fluid conduit 345 and a portion 390 of the expandable tubular member 375 below the expansion cone 375. The fifth fluid conduit 355 is further preferably contained within the third support member 350. The fifth fluid conduit 355 is preferably adapted to convey fluidic materials such as, for example, drilling muds, water, and lubricants at

operating pressures and flow rates ranging from about 0 to 12,000 psi and 0 to 500 gallons/minute in order to optimally propagate the expansion cone 375.

The sealing members 360 are preferably coupled to the housing 315. The sealing members 360 are preferably adapted to seal the interface between the exterior surface of the housing 315 and the interior surface of the expandable tubular member 370. In this manner, the interior portion 385 of the expandable tubular member 375 is fluidicly isolated from the exterior region above the housing 315. The sealing members 360 may be any number of conventional commercially available sealing members. The sealing members 360 are conventional O-ring sealing members available from various commercial suppliers in order to optimally provide a high pressure seal.

The locking member 365 is preferably coupled to the housing 315. The locking member 365 is further preferably releasably coupled to the expandable tubular member 370. In this manner, the housing 365 is controllably coupled to the expandable tubular member 370. In this manner, the housing 365 is preferably released from the expandable tubular member 370 upon the completion of the radial expansion of the expandable tubular member 370. The locking member 365 may be any number of conventional commercially available releasable locking members. The locking member 365 is an electrically releasable locking member in order to optimally provide an easily retrievable running expansion system.

T locking member 365 is replaced by or supplemented by one or more conventional shear pins in order to provide an alternative means of controllably releasing the housing 315 from the expandable tubular member 370.

The expandable tubular member 370 is releasably coupled to the locking member 365. The expandable tubular member 370 is preferably adapted to be radially expanded by the axial displacement of the expansion cone 375.

As illustrated in FIG. 4, the expandable tubular member 370 includes a tubular body 405 having an interior region 410, an exterior surface 415, a first end 420, an intermediate portion 425, and a second end 430. The tubular member 370 further preferably includes the sealing member 380.

(

The tubular body 405 of the tubular member 370 preferably has a substantially annular cross section. The tubular body 405 may be fabricated from any number of conventional commercially available materials such as, for example, Oilfield Country Tubular Goods (OCTG), 13 chromium steel, 4140 steel, or automotive grade steel tubing/casing, or L83, J55, or P110 API casing. The tubular body 405 of the tubular member 370 is further provided substantially as disclosed in one or more of the following co-pending U.S. patent applications:

Provisional Patent Application Number	Attorney Docket No.	Filing Date
60/108,558	25791.9	11-16-1998
60/111,293	25791.3	12-7-1998
60/119,611	25791.8	2-11-1999
60/121,702	25791.7	2-25-1999
60/121,841	25791.12	2-26-1999
60/121,907	25791.16	2-26-1999
60/124,042	25791.11	3-11-1999
60/131,106	25791.23	4-26-1999
60/137,998	25791.17	6-7-1999
60/143,039	25791.26	7-9-1999
60/146,203	25791.25	7-29-1999
60/154,047	25791.29	9-16-1999
60/159,082	25791.34	10-12-1999
60/159,039	25791.36	10-12-1999
60/159,033	25791.37	10-12-1999

The interior region 410 of the tubular body 405 preferably has a substantially circular cross section. The interior region 410 of the tubular body 405 preferably

includes a first inside diameter D_1, an intermediate inside diameter D_{INT}, and a second inside diameter D_2. The first and second inside diameters, D_1 and D_2, are substantially equal. The first and second inside diameters, D_1 and D_2, are greater than the intermediate inside diameter D_{INT}.

The first end 420 of the tubular body 405 is coupled to the intermediate portion 425 of the tubular body 405. The exterior surface of the first end 420 of the tubular body 405 preferably further includes a protective coating fabricated from tungsten carbide, or other similar wear resistant materials in order to protect the first end 420 of the tubular body 405 during placement of the repair apparatus 300 within the wellbore casing 100. The outside diameter of the first end 420 of the tubular body 405 is greater than the outside diameter of the intermediate portion 425 of the tubular body 405. In this manner, the sealing member 380 is optimally protected during placement of the tubular member 370 within the wellbore casing 100. The outside diameter of the first end 420 of the tubular body 405 is substantially equal to the outside diameter of the second end 430 of the tubular body 405. In this manner, the sealing member 380 is optimally protected during placement of the tubular member 370 within the wellbore casing 100. The outside diameter of the first end 420 of the tubular member 370 is adapted to permit insertion of the tubular member 370 into the typical range of wellbore casings. The first end 420 of the tubular member 370 includes a wall thickness t_1.

The intermediate portion 425 of the tubular body 405 is coupled to the first end 420 of the tubular body 405 and the second end 430 of the tubular body 405. The intermediate portion 425 of the tubular body 405 preferably includes the sealing member 380. The outside diameter of the intermediate portion 425 of the tubular body 405 is less than the outside diameter of the first and second ends, 420 and 430, of the tubular body 405. In this manner, the sealing member 380 is optimally protected during placement of the tubular member 370 within the wellbore casing 100. The outside diameter of the intermediate portion 425 of the tubular body 405 ranges from about 75% to 98% of the outside diameters of the first and second ends, 420 and 430, in order to optimally protect the sealing member 380 during placement

of the tubular member 370 within the wellbore casing 100. The intermediate portion 425 of the tubular body 405 includes a wall thickness t_{INT}.

The second end 430 of the tubular body 405 is coupled to the intermediate portion 425 of the tubular body 405. The exterior surface of the second end 430 of the tubular body 405 preferably further includes a protective coating fabricated from a wear resistant material such as, for example, tungsten carbide in order to protect the second end 430 of the tubular body 405 during placement of the repair apparatus 300 within the wellbore casing 100. The outside diameter of the second end 430 of the tubular body 405 is greater than the outside diameter of the intermediate portion 425 of the tubular body 405. In this manner, the sealing member 380 is optimally protected during placement of the tubular member 370 within a wellbore casing 100. The outside diameter of the second end 430 of the tubular body 405 is substantially equal to the outside diameter of the first end 420 of the tubular body 405. In this manner, the sealing member 380 is optimally protected during placement of the tubular member 370 within the wellbore casing 100. The outside diameter of the second end 430 of the tubular member 370 is adapted to permit insertion of the tubular member 370 into the typical range of wellbore casings. The second end 430 of the tubular member 370 includes a wall thickness t_2.

The wall thicknesses t_1 and t_2 are substantially equal in order to provide substantially equal burst strength for the first and second ends, 420 and 430, of the tubular member 370. The wall thicknesses t_1 and t_2 are both greater than the wall thickness t_{INT} in order to optimally match the burst strength of the first and second ends, 420 and 430, of the tubular member 370 with the intermediate portion 425 of the tubular member 370.

The sealing member 380 is preferably coupled to the outer surface of the intermediate portion 425 of the tubular body 405. The sealing member 380 preferably seals the interface between the intermediate portion 425 of the tubular body 405 and interior surface of the wellbore casing 100 after radial expansion of the intermediate portion 425 of the tubular body 405. The sealing member 380 preferably has a substantially annular cross section. The outside diameter of the

sealing member 380 is preferably selected to be less than the outside diameters of the first and second ends, 420 and 430, of the tubular body 405 in order to optimally protect the sealing member 380 during placement of the tubular member 370 within the typical range of wellbore casings 100. The sealing member 380 may be fabricated from any number of conventional commercially available materials such as, for example, thermoset or thermoplastic polymers. The sealing member 380 is fabricated from thermoset polymers in order to optimally seal the interface between the radially expanded intermediate portion 425 of the tubular body 405 and the wellbore casing 100.

During placement of the tubular member 370 within the wellbore casing 100, the protective coatings provided on the exterior surfaces of the first and second ends, 420 and 430, of the tubular body 405 prevent abrasion with the interior surface of the wellbore casing 100. After radial expansion of the tubular body 405, the sealing member 380 seals the interface between the outside surface of the intermediate portions 425 of the tubular body 405 of the tubular member 370 and the inside surface of the wellbore casing 100. During placement of the tubular member 370 within the wellbore casing 100, the sealing member 380 is preferably protected from contact with the interior walls of the wellbore casing 100 by the recessed outer surface profile of the tubular member 370.

The tubular body 405 of the tubular member 370 further includes first and second transition portions, 435 and 440, coupled between the first and second ends, 420 and 430, and the intermediate portion 425 of the tubular body 405. The first and second transition portions, 435 and 440, are inclined at an angle, α, relative to the longitudinal direction ranging from about 0 to 30 degrees in order to optimally facilitate the radial expansion of the tubular member 370. The first and second transition portions, 435 and 440, provide a smooth transition between the first and second ends, 420 and 440, and the intermediate portion 425, of the tubular body 405 of the tubular member 370 in order to minimize stress concentrations.

Referring to FIG. 5, The tubular member 370 is formed by a process 500 that includes the steps of: (1) expanding both ends of the tubular body 405 in step 505;

(2) stress relieving both radially expanded ends of the tubular body 405 in step 510; and (3) putting a sealing material on the outside diameter of the non-expanded intermediate portion 425 of the tubular body 405 in step 515. The process 500 further includes the step of putting layers of protective coatings onto the exterior surfaces of the radially expanded ends, 420 and 430, of the tubular body 405.

In steps 505 and 510, both ends, 420 and 430, of the tubular body 405 are radially expanded using conventional radial expansion methods, and then both ends, 420 and 430, of the tubular body 405 are stress relieved. The radially expanded ends, 420 and 430, of the tubular body 405 include interior diameters D_1 and D_2. The interior diameters D_1 and D_2 are substantially equal in order to provide a burst strength that is substantially equal. The ratio of the interior diameters D_1 and D_2 to the interior diameter D_{INT} of the tubular body 405 ranges from about 100% to 120% in order to optimally provide a tubular member for subsequent radial expansion.

The relationship between the wall thicknesses t_1, t_2, and t_{INT} of the tubular body 405; the inside diameters D_1, D_2 and D_{INT} of the tubular body 405; the inside diameter $D_{wellbore}$ of the wellbore casing 100 that the tubular body 405 will be inserted into; and the outside diameter D_{cone} of the expansion cone 375 that will be used to radially expand the tubular body 405 within the wellbore casing 100 is given by the following expression:

$$Dwellbore - 2 * t_1 \geq D_1 \geq \frac{1}{t_1}\left[(t_1 - t_{INT}) * D_{cone} + t_{INT} * D_{INT}\right] \quad (1)$$

where $t_1 = t_2$; and

$D_1 = D_2$.

By satisfying the relationship given in equation (1), the expansion forces placed upon the tubular body 405 during the subsequent radial expansion process are substantially equalized. More generally, the relationship given in equation (1) may be used to calculate the optimal geometry for the tubular body 405 for subsequent radial expansion of the tubular body 405 for fabricating and/or repairing a wellbore casing, a pipeline, or a structural support.

In step 515, the sealing member 380 is then applied onto the outside diameter of the non-expanded intermediate portion 425 of the tubular body 405. The sealing member 380 may be applied to the outside diameter of the non-expanded intermediate portion 425 of the tubular body 405 using any number of conventional commercially available methods. The sealing member 380 is applied to the outside diameter of the intermediate portion 425 of the tubular body 405 using commercially available chemical and temperature resistant adhesive bonding.

As illustrated in FIG. 6, the interior surface of the tubular body 405 of the tubular member 370 further includes a coating 605 of a lubricant. The coating 605 of lubricant may be applied using any number of conventional methods such as, for example, dipping, spraying, sputter coating or electrostatic deposition. The coating 605 of lubricant is chemically, mechanically, and/or adhesively bonded to the interior surface of the tubular body 405 of the tubular member 370 in order to optimally provide a durable and consistent lubricating effect. The force that bonds the lubricant to the interior surface of the tubular body 405 of the tubular member 370 is greater than the shear force applied during the radial expansion process.

The coating 605 of lubricant is applied to the interior surface of the tubular body 405 of the tubular member 370 by first applying a phenolic primer to the interior surface of the tubular body 405 of the tubular member 370, and then bonding the coating 605 of lubricant to the phenolic primer using an antifriction paste including the coating 605 of lubricant carried within an epoxy resin. The antifriction paste includes, by weight, 40-80% epoxy resin, 15-30% molybdenum disulfide, 10-15% graphite, 5-10% aluminum, 5-10% copper, 8-15% alumisilicate, and 5-10% polyethylenepolyamine. The antifriction paste is provided substantially as disclosed in U.S. Patent No. 4,329,238, the disclosure of which is incorporate herein by reference.

The coating 605 of lubricant may be any number of conventional commercially available lubricants such as, for example, metallic soaps or zinc phosphates. The coating 605 of lubricant includes C-Lube-10, C-Phos-52, C-Phos-58-M, and/or C-Phos-58-R in order to optimally provide a coating of lubricant. The

coating 605 of lubricant provides a sliding coefficient of friction less than about 0.20 in order to optimally reduce the force required to radially expand the tubular member 370 using the expansion cone 375.

The coating 605 includes a first part of a lubricant. The first part of the lubricant forms a first part of a metallic soap. The first part of the lubricant coating includes zinc phosphate. The second part of the lubricant is circulated within a fluidic carrier that is circulated into contact with the coating 605 of the first part of the lubricant during the radial expansion of the tubular member 370. The first and second parts of the lubricant react to form a lubricating layer between the interior surface of the tubular body 405 of the tubular member 370 and the exterior surface of the expansion cone 375 during the radial expansion process. In this manner, a lubricating layer is optimally provided in the exact concentration, exactly when and where it is needed. Furthermore, because the second part of the lubricant is circulated in a carrier fluid, the dynamic interface between the interior surface of the tubular body 405 of the tubular members 370 and the exterior surface of the expansion cone 375 is also preferably provided with hydrodynamic lubrication. The first and second parts of the lubricant react to form a metallic soap. The second part of the lubricant is sodium stearate.

The expansion cone 375 is movably coupled to the second support member 340. The expansion cone 375 is preferably adapted to be axially displaced upon the pressurization of the interior region 385 of the expandable tubular member 370. The expansion cone 375 is further preferably adapted to radially expand the expandable tubular member 370.

As illustrated in FIG. 7, the expansion cone 375 includes a conical outer surface 705 for radially expanding the tubular member 370 having an angle of attack α. As illustrated in FIG. 8, the angle of attack α ranges from about 10 to 40 degrees in order to minimize the required operating pressure of the interior portion 385 during the radial expansion process.

Referring to FIG. 9, an expansion cone 900 for use in the repair apparatus 300 includes a front end 905, a rear end 910, and a radial expansion section 915.

When the expansion cone 900 is displaced in the longitudinal direction relative to the tubular member 370, the interaction of the exterior surface of the radial expansion section 915 with the interior surface of the tubular member 370 causes the tubular member 370 to expand in the radial direction.

The radial expansion section 915 preferably includes a leading radial expansion section 920 and a trailing radial expansion section 925. The leading and trailing radial expansion sections, 920 and 925, have substantially conical outer surfaces. The leading and trailing radial expansion sections, 920 and 925, have corresponding angles of attack, α_1 and α_2 The angle of attack α_1 of the leading radial expansion section 920 is greater than the angle of attack α_2 of the trailing radial expansion section 925 in order to optimize the radial expansion of the tubular member 370. More generally, the radial expansion section 915 may include one or more intermediate radial expansion sections positioned between the leading and trailing radial expansion sections, 920 and 925, wherein the corresponding angles of attack α increase in stepwise fashion from the leading radial expansion section 920 to the trailing radial expansion section 925.

Referring to FIG. 10, an expansion cone 1000 for use in the repair apparatus 300 includes a front end 1005, a rear end 1010, and a radial expansion section 1015. When the expansion cone 1000 is displaced in the longitudinal direction relative to the tubular member 370, the interaction of the exterior surface of the radial expansion section 1015 with the interior surface of the tubular member 370 causes the tubular member 370 to expand in the radial direction.

The radial expansion section 1015 preferably includes an outer surface 1020 having a substantially parabolic outer profile. In this manner, the outer surface 1020 provides an angle of attack that constantly decreases from a maximum at the front end 1005 of the expansion cone 1000 to a minimum at the rear end 1010 of the expansion cone 1000. The parabolic outer profile of the outer surface 1020 may be formed using a plurality of adjacent discrete conical sections and/or using a continuous curved surface. In this manner, the area of the outer surface 1020 adjacent to the front end 1005 of the expansion cone 1000 optimally radially

overexpands the intermediate portion 425 of the tubular body 405 of the tubular member 370, while the area of the outer surface 1020 adjacent to the rear end 1010 of the expansion cone 1000 optimally radially overexpands the pre-expanded first and second ends, 420 and 430, of the tubular body 405 of the tubular member 370. The parabolic profile of the outer surface 1020 is selected to provide an angle of attack that ranges from about 8 to 20 degrees in the vicinity of the front end 1005 of the expansion cone 1000 and an angle of attack in the vicinity of the rear end 1010 of the expansion cone 1000 from about 4 to 15 degrees.

Referring to FIG. 11, the lubrication of the interface between the expansion cone 370 and the tubular member 375 during the radial expansion process will now be described. As illustrated in FIG. 31, during the radial expansion process, an expansion cone 370 radially expands the tubular member 375 by moving in an axial direction 1110 relative to the tubular member 375. The interface between the outer surface 1115 of the tapered conical portion 1120 of the expansion cone 370 and the inner surface 1125 of the tubular member 375 includes a leading edge portion 1130 and a trailing edge portion 1135.

During the radial expansion process, the leading and trailing edge portions, 1130 and 1135, are preferably lubricated by the presence of the coating 605 of lubricant. During the radial expansion process, the leading edge portion 5025 is further lubricated by the presence of lubricating fluids provided ahead of the expansion cone 370. However, because the radial clearance between the expansion cone 370 and the tubular member 375 in the trailing edge portion 1135 during the radial expansion process is typically extremely small, and the operating contact pressures between the tubular member 375 and the expansion cone 370 are extremely high, the quantity of lubricating fluid provided to the trailing edge portion 1135 is typically greatly reduced. In typical radial expansion operations, this reduction in the flow of lubricating fluids in the trailing edge portion 1135 increases the forces required to radially expand the tubular member 375.

Referring to FIG. 12, An expansion cone 1200 is used in the repair apparatus 300 that includes a front end 1200a, a rear end 1200b, a tapered portion 1205 having

an outer surface 1210, one or more circumferential grooves 1215a and 1215b, and one more internal flow passages 1220a and 1220b.

The circumferential grooves 1215 are fluidicly coupled to the internal flow passages 1220. In this manner, during the radial expansion process, lubricating fluids are transmitted from the area ahead of the front 1200a of the expansion cone 1200 into the circumferential grooves 1215. Thus, the trailing edge portion of the interface between the expansion cone 1200 and the tubular member 370 is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member 370. The lubricating fluids are injected into the internal flow passages 1220 using a fluid conduit that is coupled to the tapered end 1205 of the expansion cone 1200. Alternatively, lubricating fluids are provided for the internal flow passages 1220 using a supply of lubricating fluids provided adjacent to the front 1200a of the expansion cone 1200.

The expansion cone 1200 includes a plurality of circumferential grooves 1215. **The cross sectional area of the circumferential grooves 1215 range from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally provide lubrication to the trailing** edge portion of the interface between the expansion cone 1200 and the tubular member 370 during the radial expansion process. The expansion cone 1200 includes circumferential grooves 1215 concentrated about the axial midpoint of the tapered portion 1205 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1200 and a tubular member during the radial expansion process. The circumferential grooves 1215 are equally spaced along the trailing edge portion of the expansion cone 1200 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1200 and the tubular member 370 during the radial expansion process.

The expansion cone 1200 includes a plurality of flow passages 1220 coupled to each of the circumferential grooves 1215. The cross-sectional area of the flow passages 1220 ranges from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally provide lubrication to the trailing edge portion of the interface between the

(

expansion cone 1200 and the tubular member 370 during the radial expansion process. The cross sectional area of the circumferential grooves 1215 is greater than the cross sectional area of the flow passage 1220 in order to minimize resistance to fluid flow.

Referring to FIG. 13, an expansion cone 1300 is used in the repair apparatus 300 that includes a front end 1300a and a rear end 1300b, includes a tapered portion 1305 having an outer surface 1310, one or more circumferential grooves 1315a and 1315b, and one or more axial grooves 1320a and 1320b.

The circumferential grooves 1315 are fluidicly coupled to the axial groves 1320. In this manner, during the radial expansion process, lubricating fluids are transmitted from the area ahead of the front 1300a of the expansion cone 1300 into the circumferential grooves 1315. Thus, the trailing edge portion of the interface between the expansion cone 1300 and the tubular member 370 is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member 370. The axial grooves 1320 are provided with lubricating fluid using a supply of lubricating fluid positioned proximate the front end 1300a of the expansion cone 1300. The circumferential grooves 1315 are concentrated about the axial midpoint of the tapered portion 1305 of the expansion cone 1300 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1300 and the tubular member 370 during the radial expansion process. The circumferential grooves 1315 are equally spaced along the trailing edge portion of the expansion cone 1300 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1300 and the tubular member 370 during the radial expansion process.

The expansion cone 1300 includes a plurality of circumferential grooves 1315. The cross sectional area of the circumferential grooves 1315 range from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1300 and the tubular member 370 during the radial expansion process.

The expansion cone 1300 includes a plurality of axial grooves 1320 coupled to each of the circumferential grooves 1315. The cross sectional area of the axial grooves 1320 ranges from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1300 and the tubular member 370 during the radial expansion process. The cross sectional area of the circumferential grooves 1315 is greater than the cross sectional area of the axial grooves 1320 in order to minimize resistance to fluid flow. The axial groves 1320 are spaced apart in the circumferential direction by at least about 3 inches in order to optimally provide lubrication during the radial expansion process.

Referring to FIG. 14, an expansion cone 1400 is used in the repair apparatus 300 that includes a front end 1400a and a rear end 1400b, includes a tapered portion 1405 having an outer surface 1410, one or more circumferential grooves 1415a and 1415b, and one or more internal flow passages 1420a and 1420b.

The circumferential grooves 1415 are fluidicly coupled to the internal flow passages 1420. In this manner, during the radial expansion process, lubricating fluids are transmitted from the areas in front of the front 1400a and/or behind the rear 1400b of the expansion cone 1400 into the circumferential grooves 1415. Thus, the trailing edge portion of the interface between the expansion cone 1400 and the tubular member 370 is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member 370. Furthermore, the lubricating fluids also preferably pass to the area in front of the expansion cone 1400. In this manner, the area adjacent to the front 1400a of the expansion cone 1400 is cleaned of foreign materials. The lubricating fluids are injected into the internal flow passages 1420 by pressurizing the area behind the rear 1400b of the expansion cone 1400 during the radial expansion process.

The expansion cone 1400 includes a plurality of circumferential grooves 1415. The cross sectional area of the circumferential grooves 1415 ranges from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 respectively, in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1400 and the

tubular member 370 during the radial expansion process. The expansion cone 1400 includes circumferential grooves 1415 that are concentrated about the axial midpoint of the tapered portion 1405 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1400 and the tubular member 370 during the radial expansion process. The circumferential grooves 1415 are equally spaced along the trailing edge portion of the expansion cone 1400 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1400 and the tubular member 370 during the radial expansion process.

The expansion cone 1400 includes a plurality of flow passages 1420 coupled to each of the circumferential grooves 1415. The flow passages 1420 fluidicly couple the front end 1400a and the rear end 1400b of the expansion cone 1400. The cross-sectional area of the flow passages 1420 ranges from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1400 and the tubular member 370 during the radial expansion process. The cross sectional area of the circumferential grooves 1415 is greater than the cross-sectional area of the flow passages 1420 in order to minimize resistance to fluid flow.

Referring to FIG. 15, an expansion cone 1500 is used in the apparatus that includes a front end 1500a and a rear end 1500b, includes a tapered portion 1505 having an outer surface 1510, one or more circumferential grooves 1515a and 1515b, and one or more axial grooves 1520a and 1520b.

The circumferential grooves 1515 are fluidicly coupled to the axial grooves 1520. In this manner, during the radial expansion process, lubricating fluids are transmitted from the areas in front of the front 1500a and/or behind the rear 1500b of the expansion cone 1500 into the circumferential grooves 1515. Thus, the trailing edge portion of the interface between the expansion cone 1500 and the tubular member 370 is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member 370. Furthermore, pressurized lubricating fluids pass from the fluid passages 1520 to the area in front

of the front 1500a of the expansion cone 1500. In this manner, the area adjacent to the front 1500a of the expansion cone 1500 is cleaned of foreign materials. The lubricating fluids are injected into the internal flow passages 1520 by pressurizing the area behind the rear 1500b expansion cone 1500 during the radial expansion process.

The expansion cone 1500 includes a plurality of circumferential grooves 1515. The cross sectional area of the circumferential grooves 1515 range from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1500 and the tubular member 370 during the radial expansion process. The expansion cone 1500 includes circumferential grooves 1515 that are concentrated about the axial midpoint of the tapered portion 1505 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1500 and the tubular member 370 during the radial expansion process. The circumferential grooves 1515 are equally spaced along the trailing edge portion of the expansion cone 1500 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1500 and the tubular member 370 during the radial expansion process.

The expansion cone 1500 includes a plurality of axial grooves 1520 coupled to each of the circumferential grooves 1515. The axial grooves 1520 fluidicly couple the front end and the rear end of the expansion cone 1500. The cross sectional area of the axial grooves 1520 range from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2, respectively, in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1500 and the tubular member 370 during the radial expansion process. The cross sectional area of the circumferential grooves 1515 is greater than the cross sectional area of the axial grooves 1520 in order to minimize resistance to fluid flow. The axial grooves 1520 are spaced apart in the circumferential direction by at least about 3 inches in order to optimally provide lubrication during the radial expansion process.

(

Referring to FIG. 16, an expansion cone 1600 is used in the repair apparatus 300 that includes a front end 1600a and a rear end 1600b, includes a tapered portion 1605 having an outer surface 1610, one or more circumferential grooves 1615a and 1615b, and one or more axial grooves 1620a and 1620b.

The circumferential grooves 1615 are fluidicly coupled to the axial grooves 1620. In this manner, during the radial expansion process, lubricating fluids are transmitted from the area ahead of the front 1600a of the expansion cone 1600 into the circumferential grooves 1615. Thus, the trailing edge portion of the interface between the expansion cone 1600 and a tubular member is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member 370. The lubricating fluids are injected into the axial grooves 1620 using a fluid conduit that is coupled to the tapered end 3205 of the expansion cone 1600.

The expansion cone 1600 includes a plurality of circumferential grooves 1615. **The cross sectional area of the circumferential grooves 1615 ranges from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally provide lubrication to the trailing** edge portion of the interface between the expansion cone 1600 and the tubular member 370 during the radial expansion process. The expansion cone 1600 includes circumferential grooves 1615 that are concentrated about the axial midpoint of the tapered portion 1605 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1600 and the tubular member 370 during the radial expansion process. The circumferential grooves 1615 are equally spaced along the trailing edge portion of the expansion cone 1600 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1600 and the tubular member 370 during the radial expansion process.

The expansion cone 1600 includes a plurality of axial grooves 1620 coupled to each of the circumferential grooves 1615. The axial grooves 1620 intersect each of the circumferential groves 1615 at an acute angle. The cross sectional area of the axial grooves 1620 ranges from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally

provide lubrication to the trailing edge portion of the interface between the expansion cone 1600 and the tubular member 370 during the radial expansion process. The cross sectional area of the circumferential grooves 1615 is greater than the cross sectional area of the axial grooves 1620. The axial grooves 1620 are spaced apart in the circumferential direction by at least about 3 inches in order to optimally provide lubrication during the radial expansion process. The axial grooves 1620 intersect the longitudinal axis of the expansion cone 1600 at a larger angle than the angle of attack of the tapered portion 1605 in order to optimally provide lubrication during the radial expansion process.

Referring to FIG. 17, an expansion cone 1700 is used in the repair apparatus 300 that includes a front end 1700a and a rear end 1700b, includes a tapered portion 1705 having an outer surface 1710, a spiral circumferential groove 1715, and one or more internal flow passages 1720.

The circumferential groove 1715 is fluidicly coupled to the internal flow passage 1720. In this manner, during the radial expansion process, lubricating fluids are transmitted from the area ahead of the front 1700a of the expansion cone 1700 into the circumferential groove 1715. Thus, the trailing edge portion of the interface between the expansion cone 1700 and the tubular member 370 is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member. The lubricating fluids are injected into the internal flow passage 1720 using a fluid conduit that is coupled to the tapered end 1705 of the expansion cone 1700.

The expansion cone 1700 includes a plurality of spiral circumferential grooves 1715. The cross sectional area of the circumferential groove 1715 ranges from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1700 and the tubular member 370 during the radial expansion process. The expansion cone 1700 includes circumferential grooves 1715 that are concentrated about the axial midpoint of the tapered portion 1705 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1700 and the tubular

member 370 during the radial expansion process. The circumferential grooves 1715 are equally spaced along the trailing edge portion of the expansion cone 1700 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1700 and the tubular member 370 during the radial expansion process.

The expansion cone 1700 includes a plurality of flow passages 1720 coupled to each of the circumferential grooves 1715. The cross-sectional area of the flow passages 1720 ranges from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1700 and the tubular member 370 during the radial expansion process. The cross sectional area of the circumferential groove 1715 is greater than the cross sectional area of the flow passage 1720 in order to minimize resistance to fluid flow.

Referring to FIG. 18, an expansion cone 1800 is used in the repair apparatus 300 that includes a front end 1800a and a rear end 1800b, includes a tapered portion 1805 having an outer surface 1810, a spiral circumferential groove 1815, and one or more axial grooves 1820a, 1820b and 1820c.

The circumferential groove 1815 is fluidicly coupled to the axial grooves 1820. In this manner, during the radial expansion process, lubricating fluids are transmitted from the area ahead of the front 1800a of the expansion cone 1800 into the circumferential groove 1815. Thus, the trailing edge portion of the interface between the expansion cone 1800 and a tubular member is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member 370. The lubricating fluids are injected into the axial grooves 1820 using a fluid conduit that is coupled to the tapered end 1805 of the expansion cone 1800.

The expansion cone 1800 includes a plurality of spiral circumferential grooves 1815. The cross sectional area of the circumferential grooves 1815 range from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1800 and the

tubular member 370 during the radial expansion process. The expansion cone 1800 includes circumferential grooves 1815 concentrated about the axial midpoint of the tapered portion 1805 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1800 and the tubular member 370 during the radial expansion process. The circumferential grooves 1815 are equally spaced along the trailing edge portion of the expansion cone 1800 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1800 and the tubular member 370 during the radial expansion process.

The expansion cone 1800 includes a plurality of axial grooves 1820 coupled to each of the circumferential grooves 1815. The cross sectional area of the axial grooves 1820 range from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1800 and the tubular member 370 during the radial expansion process. The axial grooves 1820 intersect the circumferential grooves 1815 in a perpendicular manner. The cross sectional area of the circumferential groove 1815 is greater than the cross sectional area of the axial grooves 1820 in order to minimize resistance to fluid flow. The circumferential spacing of the axial grooves is greater than about 3 inches in order to optimally provide lubrication during the radial expansion process. The axial grooves 1820 intersect the longitudinal axis of the expansion cone at an angle greater than the angle of attack of the tapered portion 1805 in order to optimally provide lubrication during the radial expansion process.

Referring to FIG. 19, an expansion cone 1900 is used in the repair apparatus 300 that includes a front end 1900a and a rear end 1900b, includes a tapered portion 1905 having an outer surface 1910, a circumferential groove 1915, a first axial groove 1920, and one or more second axial grooves 1925a, 1925b, 1925c and 1925d.

The circumferential groove 1915 is fluidicly coupled to the axial grooves 1920 and 1925. In this manner, during the radial expansion process, lubricating fluids are preferably transmitted from the area behind the back 1900b of the

expansion cone 1900 into the circumferential groove 1915. Thus, the trailing edge portion of the interface between the expansion cone 1900 and the tubular member 370 is provided with an increased supply of lubricant, thereby reducing the amount of force required to radially expand the tubular member 370. The lubricating fluids are injected into the first axial groove 1920 by pressurizing the region behind the back 1900b of the expansion cone 1900. The lubricant is further transmitted into the second axial grooves 1925 where the lubricant preferably cleans foreign materials from the tapered portion 1905 of the expansion cone 1900.

The expansion cone 1900 includes a plurality of circumferential grooves 1915. The cross sectional area of the circumferential groove 1915 ranges from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1900 and the tubular member 370 during the radial expansion process. The expansion cone 1900 includes circumferential grooves 1915 concentrated about the axial midpoint of the tapered portion 1905 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1900 and the tubular member 370 during the radial expansion process. The circumferential grooves 1915 are equally spaced along the trailing edge portion of the expansion cone 1900 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1900 and the tubular member 370 during the radial expansion process.

The expansion cone 1900 includes a plurality of first axial grooves 1920 coupled to each of the circumferential grooves 1915. The first axial grooves 1920 extend from the back 1900b of the expansion cone 1900 and intersect the circumferential groove 1915. The cross sectional area of the first axial groove 1920 ranges from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1900 and the tubular member 370 during the radial expansion process. The first axial groove 1920 intersects the circumferential groove 1915 in a perpendicular manner. The cross sectional area of the circumferential groove 1915 is greater than the cross

sectional area of the first axial groove 1920 in order to minimize resistance to fluid flow. The circumferential spacing of the first axial grooves 1920 is greater than about 3 inches in order to optimally provide lubrication during the radial expansion process.

The expansion cone 1900 includes a plurality of second axial grooves 1925 coupled to each of the circumferential grooves 1915. The second axial grooves 1925 extend from the front 1900a of the expansion cone 1900 and intersect the circumferential groove 1915. The cross sectional area of the second axial grooves 1925 ranges from about $2X10^{-4}$ in^2 to $5X10^{-2}$ in^2 in order to optimally provide lubrication to the trailing edge portion of the interface between the expansion cone 1900 and the tubular member 370 during the radial expansion process. The second axial grooves 1925 intersect the circumferential groove 1915 in a perpendicular manner. The cross sectional area of the circumferential groove 1915 is greater than the cross sectional area of the second axial grooves 1925 in order to minimize resistance to fluid flow. The circumferential spacing of the second axial grooves 1925 is greater than about 3 inches in order to optimally provide lubrication during the radial expansion process. The second axial grooves 1925 intersect the longitudinal axis of the expansion cone 1900 at an angle greater than the angle of attack of the tapered portion 1905 in order to optimally provide lubrication during the radial expansion process.

Referring to Fig. 20, The first axial groove 1920 includes a first portion 2005 having a first radius of curvature 2010, a second portion 2015 having a second radius of curvature 2020, and a third portion 2025 having a third radius of curvature 2030. The radius of curvatures, 2010, 2020 and 2030 are substantially equal. The radius of curvatures, 2010, 2020 and 2030 are all substantially equal to 0.0625 inches.

Referring to Fig. 21, The circumferential groove 1915 includes a first portion 2105 having a first radius of curvature 2110, a second portion 2115 having a second radius of curvature 2120, and a third portion 2125 having a third radius of curvature

2130. The radius of curvatures, 2110, 2120 and 2130 are substantially equal. The radius of curvatures, 2110, 2120 and 2130 are all substantially equal to 0.125 inches.

Referring to Fig. 22, The second axial groove 1925 includes a first portion 2205 having a first radius of curvature 2210, a second portion 2215 having a second radius of curvature 2220, and a third portion 2225 having a third radius of curvature 2230. The first radius of curvature 2210 is greater than the third radius of curvature 2230. The first radius of curvature 2210 is equal to 0.5 inches, the second radius of curvature 2220 is equal to 0.0625 inches, and the third radius of curvature 2230 is equal to 0.125 inches.

Referring to Fig. 23, an expansion cone 2300 is used in the repair apparatus 300 that includes an internal flow passage 2305 having an insert 2310 including a flow passage 2315. The cross sectional area of the flow passage 2315 is less than the cross sectional area of the flow passage 2305. More generally, A plurality of inserts 2310 are provided, each with different sizes of flow passages 2315. In this manner, the flow passage 2305 is machined to a standard size, and the lubricant supply is varied by using different sized inserts 2310. The teachings of the expansion cone 2300 are incorporated into the expansion cones 1200, 1300, 1400, and 1700.

Referring to Fig. 24, The insert 2310 includes a filter 2405 for filtering particles and other foreign materials from the lubricant that passes into the flow passage 2305. In this manner, the foreign materials are prevented from clogging the flow passage 2305 and other flow passages within the expansion cone 2300.

The increased lubrication provided to the trailing edge portion of the expansion cones 1200, 1300, 1400, 1500, 1600, 1700, 1800, and 1900 greatly reduces the amount of galling or seizure caused by the interface between the expansion cones and the tubular member 370 during the radial expansion process thereby permitting larger continuous sections of tubulars to be radially expanded in a single continuous operation. Thus, use of the expansion cones 1200, 1300, 1400, 1500, 1600, 1700, 1800, and 1900 reduces the operating pressures required for radial expansion and thereby reduces the size of the pump 325. In addition, failure,

bursting, and/or buckling of the tubular member 370 during the radial expansion process is significantly reduced, and the success ratio of the radial expansion process is greatly increased.

The lubricating fluids used with the expansion cones 1200, 1300, 1400, 1500, 1600, 1700, 1800 and 1900 for expanding the tubular member 370 have viscosities ranging from about 1 to 10,000 centipoise in order to optimize the injection of the lubricating fluids into the circumferential grooves of the expansion cones during the radial expansion process. The lubricating fluids used with the expansion cones 1200, 1300, 1400, 1500, 1600, 1700, 1800 and 1900 for expanding the tubular member 370 comprise various conventional lubricants available from various commercial vendors consistent with the teachings of the present disclosure in order to optimize the injection of the lubricating fluids into the circumferential grooves of the expansion cones during the radial expansion process.

As illustrated in FIG. 25, the expansion cone 375 further includes a central passage 2505 for receiving the support member 340 and the repair apparatus 300 further includes one or more sealing members 2510 and one or more bearing members 2515.

The sealing members 2510 are preferably adapted to fluidicly seal the dynamic interface between the central passage 2505 of the expansion cone 375 and the support member 340. The sealing members 2510 may be any number of conventional commercially available sealing members. The sealing members 2510 are conventional O-rings sealing members available from various commercial suppliers in order to optimally provide a fluidic seal.

The bearing members 2515 are preferably adapted to provide a sliding interface between the central passage 2505 of the expansion cone 375 and the support member 340. The bearing members 2515 may be any number of conventional commercially available bearings. The bearing members 2515 are wear bands available from Haliburton Energy Services in order to optimally provide a sliding interface that minimizes wear.

The sealing member 380 is coupled to the exterior surface of the expandable tubular member 375. The sealing member 380 is preferably adapted to fluidicly seal the interface between the expandable tubular member 375 and the wellbore casing 100 after the radial expansion of the expandable tubular member 375. The sealing member 380 may be any number of conventional commercially available sealing members. The sealing member 380 is a nitrile rubber sealing member available from Eustler, Inc. in order to optimally provide a high pressure, high load bearing seal between the expandable tubular member 375 and the casing 100.

As illustrated in FIG. 3a, During placement of the repair apparatus 300 within the wellbore casing 100, the repair apparatus 300 is supported by the support member 305. During placement of the repair apparatus 300 within the wellbore casing 100, fluidic materials within the wellbore casing 100 are conveyed to a location above the repair apparatus 300 using the fluid conduits 335, 345, and 355. In this manner, surge pressures during placement of the repair apparatus 300 within the wellbore casing 100 are minimized.

Prior to placement of the repair apparatus 300 in the wellbore, the outer surfaces of the repair apparatus 300 are coated with a lubricating fluid to facilitate their placement the wellbore and reduce surge pressures. The lubricating fluid comprises BARO-LUB GOLD-SEAL(RTM) brand drilling mud lubricant, available from Baroid(RTM) Drilling Fluids, Inc. In this manner, the insertion of the repair apparatus 300 into the wellbore casing 100 is optimized.

After placement of the repair apparatus 300 within the wellbore casing 100, in step 210, the logging tool 310 is used in a conventional manner to locate the openings 115 in the wellbore casing 100.

Once the openings 115 have been located by the logging tool 310, in step 215, the repair apparatus 300 is further positioned within the wellbore casing 100 with the sealing member 380 placed in opposition to the openings 115.

As illustrated in FIGS. 3b and 3c, After the repair apparatus 300 has been positioned with the sealing member 380 in opposition to the openings 115, in step 220, the tubular member 370 is radially expanded into contact with the wellbore

casing 100. The tubular member 370 is radially expanded by displacing the expansion cone 375 in the axial direction. The expansion cone 375 is displaced in the axial direction by pressurizing the interior portion 385. The interior portion 385 is pressurized by pumping fluidic materials into the interior portion 385 using the pump 325.

The pump 325 pumps fluidic materials from the region above and proximate to the repair apparatus 300 into the interior portion 385 using the fluidic passages 320 and 330. In this manner, the interior portion 385 is pressurized and the expansion cone 375 is displaced in the axial direction. In this manner, the tubular member 370 is radially expanded into contact with the wellbore casing 100. The interior portion 385 is pressurized to operating pressures ranging from about 0 to 12,000 psi using flow rates ranging from about 0 to 500 gallons/minute. Fluidic materials displaced by the axial movement of the expansion cone 375 are conveyed to a location above the repair apparatus 300 by the fluid conduits 335, 345, and 355. During the pumping of fluidic materials into the interior portion 385 by the pump 325, the tubular member 370 is maintained in a substantially stationary position.

As illustrated in FIG. 3d, after the completion of the radial expansion of the tubular member 370, the locking member 365 is decoupled from the tubular member 370 and the repair apparatus 300 is removed from the wellbore casing 100. During the removal of the repair apparatus 300 from the wellbore casing 100, fluidic materials above the repair apparatus 300 are conveyed to a location below the repair apparatus 300 using the fluid conduits 335, 345 and 355. In this manner, the removal of the repair apparatus 300 from the wellbore casing is facilitated.

As illustrated in FIG. 3e, The openings 115 in the wellbore casing 100 are sealed off by the radially expanded tubular member 370 and the sealing member 380. In this manner, the repair apparatus 300 provides a compact and efficient device for repairing wellbore casings. More generally, the repair apparatus 300 is used to repair and form wellbore casings, pipelines, and structural supports.

Referring to FIG. 26a, in step 205, a repair apparatus 2600 is positioned within the wellbore casing 100.

The repair apparatus 2600 preferably includes a first support member 2605, a logging tool 2610, a housing 2615, a first fluid conduit 2620, a pump 2625, a second fluid conduit 2630, a first valve 2635, a third fluid conduit 2640, a second valve 2645, a fourth fluid conduit 2650, a second support member 2655, a fifth fluid conduit 2660, the third support member 2665, a sixth fluid conduit 2670, sealing members 2675, a locking member 2680, an expandable tubular 2685, an expansion cone 2690, a sealing member 2695, a packer 2700, a seventh fluid conduit 2705, and a third valve 2710.

The first support member 2605 is preferably coupled to the logging tool 2610 and the housing 2615. The first support member 2605 is preferably adapted to be coupled to and supported by a conventional support member such as, for example, a wireline or a drill string. The first support member 2605 preferably has a substantially annular cross section in order to provide one or more conduits for conveying fluidic materials from the apparatus 2600. The first support member 2605 is further preferably adapted to convey electrical power and communication signals to the logging tool 2610, the pump 2625, the valves 2635, 2645, and 2710, and the packer 2700.

The logging tool 2610 is preferably coupled to the first support member 2605. The logging tool 2610 is preferably adapted to detect defects in the wellbore casing 100. The logging tool 2610 may be any number of conventional commercially available logging tools suitable for detecting defects in wellbore casings, pipelines, or structural supports. The logging tool 2610 is a CAST logging tool, available from Halliburton(RTM) Energy Services in order to optimally provide detection of defects in the wellbore casing 100. The logging tool 2610 is contained within the housing 2615 in order to provide a repair apparatus 2600 that is rugged and compact.

The housing 2615 is preferably coupled to the first support member 2605, the second support member 2655, the sealing members 2675, and the locking member 2680. The housing 2615 is preferably releasably coupled to the tubular member

2685. The housing 2615 is further preferably adapted to contain and support the logging tool 2610 and the pump 2625.

The first fluid conduit 2620 is preferably fluidicly coupled to the inlet of the pump 2625, the exterior region above the housing 2615, and the second fluid conduit 2630. The first fluid conduit 2620 may be contained within the first support member 2605 and the housing 2615. The first fluid conduit 2620 is preferably adapted to convey fluidic materials such as, for example, drilling muds, water, and lubricants at operating pressures and flow rates ranging from about 0 to 12,000 psi and 0 to 500 gallons/minute in order to optimally propagate the expansion cone 2690.

The pump 2625 is fluidicly coupled to the first fluid conduit 2620 and the third fluid conduit 2640. The pump 2625 is further preferably contained within and support by the housing 2615. The pump 2625 is preferably adapted to convey fluidic materials from the first fluid conduit 2620 to the third fluid conduit 2640 at operating pressures and flow rates ranging from about 0 to 12,000 psi and 0 to 500 gallons/minute in order to optimally provide operating pressure for propagating the expansion cone 2690. The pump 2625 may be any number of conventional commercially available pumps. The pump 2625 is a flow control pump out section, available from Halliburton(RTM) Energy Services in order to optimally provide fluid pressure for propagating the expansion cone 2690. The pump 2625 is preferably adapted to pressurize an interior portion 2715 of the expandable tubular member 2685 to operating pressures ranging from about 0 to 12,000 psi.

The second fluid conduit 2630 is fluidicly coupled to the first fluid conduit 2620 and the third fluid conduit 2640. The second fluid conduit 2630 is further preferably contained within the housing 2615. The second fluid conduit 2630 is preferably adapted to convey fluidic materials such as, for example, drilling muds, water, and lubricants at operating pressures and flow rates ranging from about 0 to 12,000 psi and 0 to 500 gallons/minute in order to optimally provide propagation of the expansion cone 2690.

The first valve 2635 is preferably adapted to controllably block the second fluid conduit 2630. In this manner, the flow of fluidic materials through the second fluid conduit 2630 is controlled. The first valve 2635 may be any number of conventional commercially available flow control valves. The first valve 2635 is a conventional ball valve available from various commercial suppliers.

The third fluid conduit 2640 is fluidicly coupled to the outlet of the pump 2625, the second fluid conduit 2630, and the fifth fluid conduit 2660. The third fluid conduit 2640 is further preferably contained within the housing 2615. The third fluid conduit 2640 is preferably adapted to convey fluidic materials such as, for example, drilling muds, water, and lubricants at operating pressures and flow rates ranging from about 0 to 12,000 psi and 0 to 500 gallons/minute in order to optimally provide propagation of the expansion cone 2690.

The second valve 2645 is preferably adapted to controllably block the third fluid conduit 2640. In this manner, the flow of fluidic materials through the third fluid conduit 2640 is controlled. The second valve 2645 may be any number of conventional commercially available flow control valves. The second valve 2645 is a conventional ball valve available from various commercial sources.

The fourth fluid conduit 2650 is fluidicly coupled to the exterior region above the housing 2615 and the interior region 2720 within the expandable tubular member 2685. The fourth fluid conduit 2650 is further preferably contained within the housing 2615. The fourth fluid conduit 2650 is preferably adapted to convey fluidic materials such as, for example, drilling muds, water, and lubricants at operating pressures and flow rates ranging from about 0 to 5,000 psi and 0 to 500 gallons/minute in order to optimally vent fluidic materials in front of the expansion cone 2690 during the radial expansion process.

The second support member 2655 is coupled to the housing 2615 and the third support member 2665. The second support member 2655 is further preferably movably and sealingly coupled to the expansion cone 2690. The second support member 2655 preferably has a substantially annular cross section in order to provide

one or more conduits for conveying fluidic materials. The second support member 2655 is centrally positioned within the expandable tubular member 2685.

The fifth fluid conduit 2660 is fluidicly coupled to the third fluid conduit 2640 and the sixth fluid conduit 2670. The fifth fluid conduit 2660 is further preferably contained within the second support member 2655. The fifth fluid conduit 2660 is preferably adapted to convey fluidic materials such as, for example, drilling muds, water, and lubricants at operating pressures and flow rates ranging from about 0 to 12,000 psi and 0 to 500 gallons/minute in order to optimally propagate the expansion cone 2690.

The third support member 2665 is coupled to the second support member 2655. The third support member 2665 is further preferably adapted to support the expansion cone 2690. The third support member 2665 preferably has a substantially annular cross section in order to provide one or more conduits for conveying fluidic materials.

The sixth fluid conduit 2670 is fluidicly coupled to the fifth fluid conduit 2660 and the interior region 2715 of the expandable tubular member 2685 below the expansion cone 2690. The sixth fluid conduit 2670 is further preferably contained within the third support member 2665. The sixth fluid conduit 2670 is preferably adapted to convey fluidic materials such as, for example, drilling muds, water, and lubricants at operating pressures and flow rates ranging from about 0 to 12,000 psi and 0 to 500 gallons/minute in order to optimally propagate the expansion cone 2690.

The sealing members 2675 are preferably coupled to the housing 2615. The sealing members 2675 are preferably adapted to seal the interface between the exterior surface of the housing 2615 and the interior surface of the expandable tubular member 2685. In this manner, the interior portion 2730 of the expandable tubular member 2685 is fluidicly isolated from the exterior region above the housing 2615. The sealing members 2675 may be any number of conventional commercially available sealing members. The sealing members 2675 are conventional O-ring

sealing members available from various commercial suppliers in order to optimally provide a pressure seal.

The locking member 2680 is preferably coupled to the housing 2615. The locking member 2680 is further preferably releasably coupled to the expandable tubular member 2685. In this manner, the housing 2615 is controllably coupled to the expandable tubular member 2685. In this manner, the housing 2615 is preferably released from the expandable tubular member 2685 upon the completion of the radial expansion of the expandable tubular member 2685. The locking member 2680 may be any number of conventional commercially available releasable locking members. The locking member 2680 is a hydraulically released slip available from various commercial vendors in order to optimally provide support during the radial expansion process.

The locking member 2680 is replaced by or supplemented by one or more conventional shear pins in order to provide an alternative means of controllably releasing the housing 2615 from the expandable tubular member 2685.

The seals 2675 and locking member 2680 are omitted.

The expandable tubular member 2685 is releasably coupled to the locking member 2680. The expandable tubular member 2685 is preferably adapted to be radially expanded by the axial displacement of the expansion cone 2690. The expandable tubular member 2685 is substantially identical to the expandable tubular member 370 described above with reference to the repair apparatus 300.

The expansion cone 2690 is movably coupled to the second support member 2655. The expansion cone 2690 is preferably adapted to be axially displaced upon the pressurization of the interior region 2715 of the expandable tubular member 2685. The expansion cone 2690 is further preferably adapted to radially expand the expandable tubular member 2685. The expansion cone 2690 is substantially identical to the expansion cone 375 described above with reference to the repair apparatus 300.

The sealing member 2695 is coupled to the exterior surface of the expandable tubular member 2685. The sealing member 2695 is preferably adapted to fluidicly

seal the interface between the expandable tubular member 2685 and the wellbore casing 100 after the radial expansion of the expandable tubular member 2685. The sealing member 2695 may be any number of conventional commercially available sealing members. The sealing member 2695 is a nitrile rubber sealing member available from Eustler, Inc. in order to optimally provide a high pressure seal between the casing 100 and the expandable tubular member 2685.

The packer 2700 is coupled to the third support member 2665. The packer 2700 is further releasably coupled to the expandable tubular member 2685. The packer 2700 is preferably adapted to fluidicly seal the interior region 2715 of the expandable tubular member 2685. In this manner, the interior region 2715 of the expandable tubular member 2685 is pressurized. The packer 2700 may be any number of conventional commercially available packer devices. The packer 2700 is an EZ Drill Packer available from Halliburton$^{(RTM)}$ Energy Services in order to optimally provide a high pressure seal below the expansion cone 2690 that can be easily removed upon the completion of the radial expansion process.

The seventh fluid conduit 2705 is fluidicly coupled to the interior region 2715 of the expandable tubular member 2685 and an exterior region below the apparatus 2600. The seventh fluid conduit 2705 is further preferably contained within the packer 2700. The seventh fluid conduit 2705 is preferably adapted to convey fluidic materials such as, for example, drilling muds, water, and lubricants at operating pressures and flow rates ranging from about 0 to 1,500 psi and 0 to 200 gallons/minute in order to optimally provide a fluid conduit that minimizes back pressure on the apparatus 2600 when the apparatus 2600 is positioned within the wellbore casing 100.

The third valve 2710 is preferably adapted to controllably block the seventh fluid conduit 2705. In this manner, the flow of fluidic materials through the seventh fluid conduit 2705 is controlled. The third valve 2710 may be any number of conventional commercially available flow control valves. The third valve 2710 is a EZ Drill one-way check valve available from Halliburton$^{(RTM)}$ Energy Services in

order to optimally provide one-way flow through the packer 2700 while providing a pressure seal during the radial expansion process.

As illustrated in FIG. 26a, During placement of the repair apparatus 2600 within the wellbore casing 100, the apparatus 2600 is supported by the support member 2605. During placement of the apparatus 2600 within the wellbore casing 100, fluidic materials within the wellbore casing 100 are conveyed to a location above the apparatus 2600 using the fluid conduits 2705, 2670, 2660, 2640, 2630, and 2620. In this manner, surge pressures during placement of the apparatus 2600 within the wellbore casing 100 are minimized.

Prior to placement of the apparatus 2600 in the wellbore casing 100, the outer surfaces of the apparatus 2600 are coated with a lubricating fluid to facilitate their placement the wellbore and reduce surge pressures. The lubricating fluid comprises BARO-LUB GOLD-SEAL(RTM) brand drilling mud lubricant, available from Baroid(RTM) Drilling Fluids, Inc. In this manner, the insertion of the apparatus 2600 into the wellbore casing 100 is optimized.

After placement of the apparatus 2600 within the wellbore casing 100, in step 210, the logging tool 2610 is used in a conventional manner to locate the openings 115 in the wellbore casing 100.

Once the openings 115 have been located by the logging tool 2610, in step 215, the apparatus 2600 is further positioned within the wellbore casing 100 with the sealing member 2695 placed in opposition to the openings 115.

As illustrated in FIGS. 26b and 26c, After the apparatus 2600 has been positioned with the sealing member 2695 in opposition to the openings 115, in step 220, the tubular member 2685 is radially expanded into contact with the wellbore casing 100. The tubular member 2685 is radially expanded by displacing the expansion cone 2690 in the axial direction. The expansion cone 2690 is displaced in the axial direction by pressurizing the interior chamber 2715. The interior chamber 2715 is pressurized by pumping fluidic materials into the interior chamber 2715 using the pump 2625.

The pump 2625 pumps fluidic materials from the region above and proximate to the apparatus 2600 into the interior chamber 2715 using the fluid conduits 2620, 2640, 2660, and 2670. In this manner, the interior chamber 2715 is pressurized and the expansion cone 2690 is displaced in the axial direction. In this manner, the tubular member 2685 is radially expanded into contact with the wellbore casing 100. The interior chamber 2715 is pressurized to operating pressures ranging from about 0 to 12,000 psi using flow rates ranging from about 0 to 500 gallons/minute. Fluidic materials within the interior chamber 2720 displaced by the axial movement of the expansion cone 2690 are conveyed to a location above the apparatus 2600 by the fluid conduit 2650. During the pumping of fluidic materials into the interior chamber 2715 by the pump 2625, the tubular member 2685 is maintained in a substantially stationary position.

As illustrated in FIG. 26d, after the completion of the radial expansion of the tubular member 2685, the locking member 2680 and packer 2700 are decoupled from the tubular member 2685, and the apparatus 2600 is removed from the wellbore casing 100. During the removal of the apparatus 2600 from the wellbore casing 100, fluidic materials above the apparatus 2600 are conveyed to a location below the apparatus 2600 using the fluid conduits 2620, 2630, 2640, 2660, and 2670. In this manner, the removal of the apparatus 2600 from the wellbore casing is facilitated.

As illustrated in FIG. 26e, The openings 115 in the wellbore casing 100 are sealed off by the radially expanded tubular member 2685 and the sealing member 2695. In this manner, the repair apparatus 2600 provides a compact and efficient device for repairing wellbore casings. More generally, the repair apparatus 2600 is used to repair and form wellbore casings, pipelines, and structural supports.

Although illustrative embodiments of the invention have been shown and described, a wide range of modification, changes and substitution is contemplated in the foregoing disclosure. In some instances, some features of the present invention may be employed without a corresponding use of the other features. Accordingly, it

is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

TABLE FOR CONVERSION TO METRIC UNITS

0 to 12,000 psi (0 to 827.3708736 bar)

0.0625 inches (0.15875 centimetre)

0.125 inches (0.3175 centimetre)

0 to 500 gallons/minute (0 to 1,892.7059 litres/minute)

2×10^{-4} in^2 to 5×10^{-2} in^2 (5.18×10^{-4} cm^2 to 12.70×10^{-2} cm^2)

CLAIMS

1. A method of coupling a first tubular member to a second tubular member, wherein the outside diameter of the first tubular member is less than the inside diameter of the second tubular member, comprising:

positioning at least a portion of the first tubular member within the second tubular member;

pressurizing a portion of the interior of the first tubular member by pumping fluidic materials proximate the first tubular member into the portion of the interior of the first tubular member;

displacing an expansion cone within the interior of the first tubular member; and

lubricating the interface between the first tubular member and the expansion cone.

2. The method of claim 1, wherein the second tubular member is selected from the group consisting of a wellbore casing, a pipeline, and a structural support.

3. The method of claim 1, wherein lubricating includes:

coating the first tubular member with a lubricant.

4. The method of claim 1, wherein lubricating includes:

injecting a lubricating fluid into the trailing edge of the interface between the first tubular member and the expansion cone.

5. The method of claim 3, wherein lubricating includes:

coating the first tubular member with a first component of a lubricant; and

circulating a second component of the lubricant into contact with the coating on the first tubular member.

6. The method of claim 1, further including:

sealing off a portion of the first tubular member.

7. An apparatus for coupling a first tubular member to a second tubular member, wherein the outside diameter of the first tubular member is less than the inside diameter of the second tubular member, comprising:

means for positioning at least a portion of the first tubular member within the second tubular member;

means for pressurizing a portion of the interior of the first tubular member by pumping fluidic materials proximate the first tubular member into the portion of the interior of the first tubular member;

means for displacing an expansion cone within the interior of the first tubular member; and

means for lubricating the interface between the first tubular member and the expansion cone.

8. The apparatus of claim 7, wherein the second tubular member is selected from the group consisting of a wellbore casing, a pipeline, and a structural support.

9. The apparatus of claim 7, further including:

means for coating the first tubular member with a lubricant.

10. The apparatus of claim 7, further including:

means for injecting a lubricating fluid into the trailing edge of the interface between the first tubular member and the expansion cone.

11. The apparatus of claim 7, further including:

means for coating the first tubular member with a first component of a lubricant; and

means for circulating a second component of the lubricant into contact with the coating on the first tubular member.

12. The apparatus of claim 7, further including:

means for sealing off a portion of the first tubular member.

13. The method of claim 1, wherein the first tubular member includes:

a sealing member coupled to the outer surface of the first tubular member.

14. The method of claim 1, wherein the first tubular member includes:

a first end having a first outer diameter;

an intermediate portion coupled to the first end having an intermediate outer diameter; and

a second end having a second outer diameter, and coupled to the intermediate portion;

wherein the first and second outer diameters are greater than the intermediate outer diameter.

15. The method of claim 1, wherein the first end, second end, and intermediate portion of the first tubular member have wall thicknesses t_1, t_2 and t_{INT} and inside diameters D_1, D_2 and D_{INT}; and wherein the relationship between the wall thicknesses t_1, t_2 and t_{INT}, the inside diameters D_1, D_2 and D_{INT}, the inside diameter D_{TUBE} of the second tubular member that the first tubular member will be inserted into, and the outer diameter D_{cone} of the expansion cone is given by the following expression:

$$D_{TUBE} - 2 * t_1 \geq D_1 \geq \frac{1}{t_1}\left[(t_1 - t_{INT}) * D_{CONE} + t_{INT} * D_{INT}\right]$$

where $t_1 = t_2$; and

$D_1 = D_2$.

16. The method of claim 14, wherein the first tubular member includes:

a sealing member coupled to the outside surface of the intermediate portion.

17. The method of claim 14, wherein the first tubular member includes:

a first transition portion coupled to the first end and the intermediate portion inclined at a first angle; and

a second transition portion coupled to the second end and the intermediate portion inclined at a second angle;

wherein the first and second angles range from 5 to 45 degrees.

18. The method of claim 1, wherein the expansion cone includes:

an expansion cone surface having an angle of attack ranging from 10 to 40 degrees.

19. The method of claim 1, wherein the expansion cone includes:

a first expansion cone surface having a first angle of attack; and

a second expansion cone surface having a second angle of attack;

wherein the first angle of attack is greater than the second angle of attack.

20. The method of claim 1, wherein the expansion cone includes:

an expansion cone surface having a substantially parabolic profile.

21. The method of claim 1, wherein the expansion cone includes:

an inclined surface including one or more lubricating grooves.

22. The method of claim 1, wherein the expansion cone includes:

one or more internal lubricating passages coupled to each of one or more lubricating grooves.

23. The apparatus of claim 7, wherein the first tubular member includes:

a sealing member coupled to the outer surface of the first tubular member.

24. The apparatus of claim 7, wherein the first tubular member includes:

a first end having a first outer diameter;

an intermediate portion coupled to the first end having an intermediate outer diameter; and

a second end having a second outer diameter and coupled to the intermediate portion;

wherein the first and second outer diameters are greater than the intermediate outer diameter.

25. The apparatus of claim 24, wherein the first end, second end, and intermediate portion of the first tubular member have wall thicknesses t_1, t_2 and t_{INT} and inside diameters D_1, D_2 and D_{INT}; and wherein the relationship between the thicknesses t_1, t_2 and t_{INT}, the inside diameter D_1, D_2 and D_{INT}; the inside diameter D_{TUBE} of the second tubular member that the first tubular member will be inserted into, and the outside diameter D_{cone} of the expansion cone is given by the following expression:

$$D_{TUBE} - 2 * t_1 \geq D_1 \geq \frac{1}{t_1}\left[(t_1 - t_{INT}) * D_{CONE} + t_{INT} * D_{INT}\right]$$

where $t_1 = t_2$; and

$D_1 = D_2$.

26. The apparatus of claim 24, wherein the first tubular member includes:

a sealing member coupled to the outside surface of the intermediate portion.

27. The apparatus of claim 24, wherein the first tubular member includes:

a first transition portion coupled to the first end and the intermediate portion inclined at a first angle; and

a second transition portion coupled to the second end and the intermediate portion inclined at a second angle;

wherein the first and second angles range from 5 to 45 degrees.

28. The apparatus of claim 7, wherein the expansion cone includes:

an expansion cone surface having an angle of attack ranging from 10 to 40 degrees.

29. The apparatus of claim 7 wherein the expansion cone includes:

a first expansion cone surface having a first angle of attack; and

a second expansion cone surface having a second angle of attack;

wherein the first angle of attack is greater than the second angel of attack.

30. The apparatus of claim 7, wherein the expansion cone includes:

an expansion cone surface having a substantially parabolic profile.

31. The apparatus of claim 7, wherein the expansion cone includes:

an inclined surface including one or more lubricating grooves.

32. The apparatus of claim 7, wherein the expansion cone includes:

one or more internal lubricating passages coupled to each of the lubricating grooves.